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FINE CERAMICS INDUSTRY BASIC ISSUES FORUM

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FINE CERAMICS INDUSTRY BASIC ISSUES FORUM

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[Selected papers presented at the Fine Ceramics Industry Basic Issues Forum held 1 Dec 89 in Tokyo]

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[Tr. Note: The term *fine ceramics* is a Japanese invention, referring to what in English has most often been called *high-tech* or *advanced ceramics*, in contradistinction from conventional ceramics. For convenience, the term *fine ceramics* is retained in this translation.]

Introduction

It was about 10 years ago that many companies moved newly into the fine ceramics industry and began doing serious development work. Hence the history of this industry is rather short. Nevertheless, fine ceramics are now used in electronic components and machine parts, in various fields. They are used mainly for their outstanding properties and functions, including electromagnetic functions, thermomechanical functions, optical functions, and biological and chemical functions. The market, as of 1987, is on the order of 1.15 trillion yen. Fine ceramics are very different--in terms of properties, manufacturing method, and applications--from conventional porcelain-based ceramics (classic ceramics), and have become a popularly targeted field for companies outside of the ceramics field who wish to diversify. The situation is thus unlike that seen today in the fields of metals or polymer materials, both of which are founded in a long history of past materials development. In the fine ceramics field, the history of development is short, and there is practically no previous base of experience or know-how to work from. Hence materials must be developed and an industrial infrastructure fashioned from the ground up. It is no exaggeration to call this a brand new industrial field.

Many issues facing the fine ceramics industry--including how to define it, where to position it, and how it should develop in the future--have been studied in the Fine Ceramics Basic Issues Forum (chaired by Seiichi Ishizaka), established in June, 1983, and a report was drafted in May, 1984. Subsequently, this forum has been active in promoting the fine ceramics industry, promoting technological development through various projects, and establishing the Fine Ceramics Center to develop materials evaluation and testing methods. Meanwhile, there have been great changes in the environment surrounding this industry, including changes in technological development predictions and the advent of high-temperature superconductors. It is against this background that the Fine Ceramics Industry Basic Issues Forum was formed in May of this year for the purpose of more firmly establishing the fine ceramics industry and developing solutions to a variety of problems, present and future. These goals are to be met through such activities as redefining a future model or image for the fine ceramics industry, further promoting technological development, standardizing materials testing and evaluating procedures, compiling (a) database(s), developing human resources and providing other kinds of industrial infrastructure, promoting international cooperation, and promoting regional development. Very exacting studies have been conducted, both in the forum proper and in a committee of specialists. The results of these studies are set forth in this report.

Chapter 1 Expectations for Fine Ceramics

1-1 Development of Fine Ceramics Industry

(1) Modern History of Fine Ceramics

Ceramics (porcelain products, pottery, etc) have been used since ancient times as materials which excel in heat resistance and corrosion resistance. Toward the end of the 19th century, ceramic materials were noted to be good electrical insulators and to be chemically stable. While this resulted in increased market demand, it also led to gradually more exacting demands for specific properties, and in due course it became impossible to adequately meet such demands with conventional ceramic materials. This resulted in the use of refined synthetic and artificial materials, leading to the advent of so-called high-tech ceramics (fine ceramics) which exhibited carefully controlled compositions, textures, and other properties.

The electromagnetic properties of fine ceramics were first elucidated around the year 1930. Fine ceramic products utilizing these properties began to be manufactured and used prior to World War II. The development of structural fine ceramics, on the other hand, began with the development of cermets (ceramic-metal composites; used today in cutting tools). Cermets were developed in the United States during the cold war following World War II as substitutes for the special steels that required rare metals available to the United States only from foreign sources, the security of which sources was thought to be in doubt.

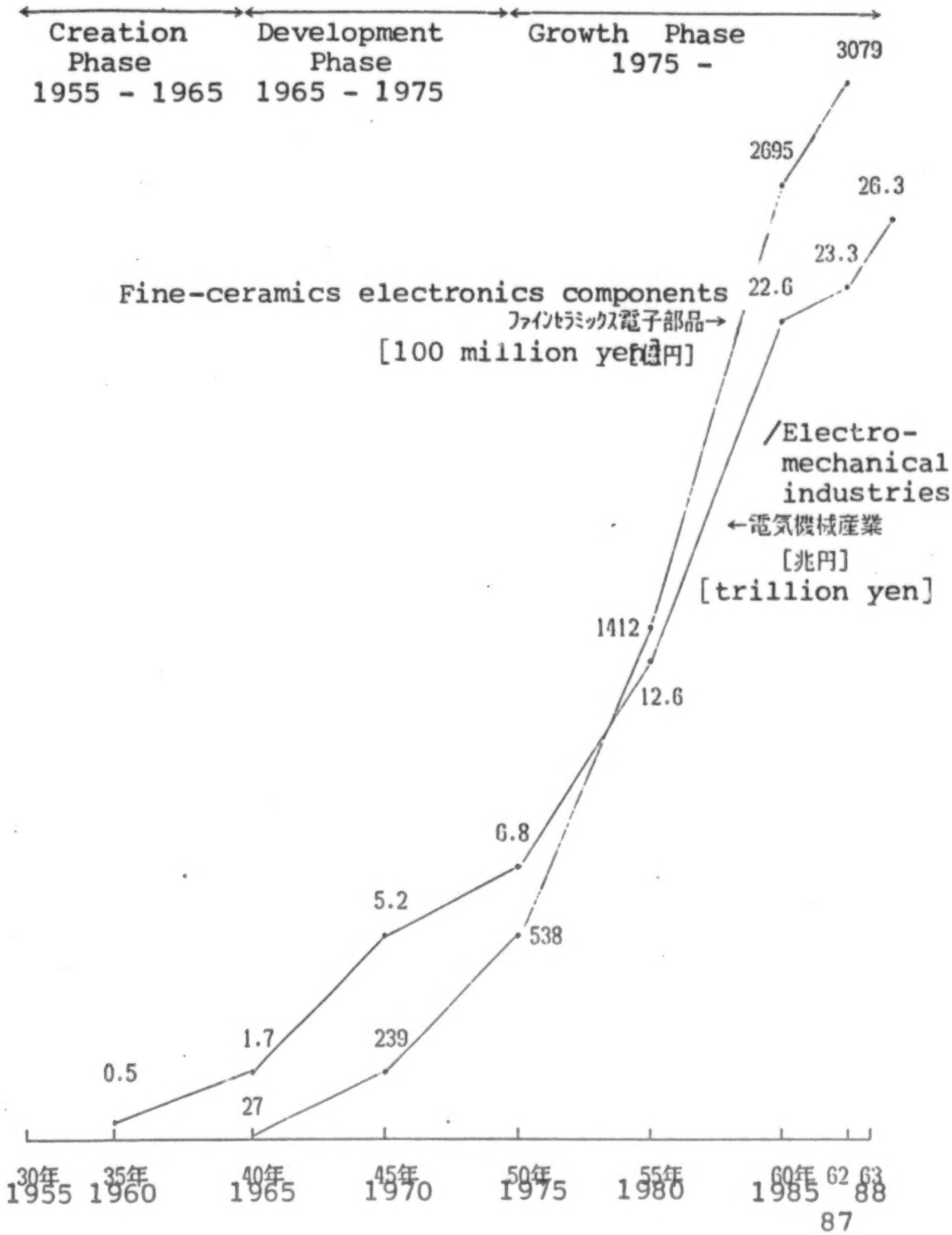
Subsequently, beginning with the oil shock of 1978, various applications of fine ceramics as structural materials were developed around the world. These included the development of materials having greater heat resistance than metals, and the use of fine ceramics in gas turbines (resulting in improved heat efficiency and energy savings), automotive parts, and as wear-resistant materials in bearings (cf Appendix 1).

(2) Development of Fine Ceramics Industry in Japan

<1> Development of Functional Materials

In Japan, ferrite research began before World War II, and research on titanium salts and barium titinate materials got underway during the war. This research was done at the Electrotechnical Laboratory. Industrial research personnel, aided by university researchers, began working with functional fine ceramic in the late 1940's and up through the early 1960's, focusing on the electromagnetic properties of barium titinate and ferrite. From the mid-1950's to the mid-1960's, research priority was directed toward developing and improving products. Production only began to grow rapidly after about 1965, however, when fine ceramics began to be used extensively in electrical and mechanical fields and to be substituted as new materials

Figure 1-1 Production Trends in Fine Ceramics Electronics Components, Electromechanical Industries



Note to Fig 1-1: Fine-ceramics electronics products: Total production among four major manufacturers for IC packages, capacitors, ferrite cores, and piezoelectric bodies. Electromechanical industries: Based on "Machine Statistics" in Production Trends & Statistics

in place of conventional materials. After 1975 we see much diversification in functional fine ceramics, and production volumes have grown since then in pace with the production growth in electromechanical industries. This view is substantiated numerically in Figure 1-1, which presents parallel graphs of main-product production growth by the four major fine ceramics electronic component manufacturers and the production trend in the electromechanical industries.

We may divide the history of fine-ceramics functional materials into three phases. From about 1945 to 1965 is the period of creation, from 1965 to 1975 the period of development (during which time the industrial infrastructure was formed), and from 1975 to the present the period of growth. In general, it takes a long time for a new technological field to develop into a viable industry, beginning with enormous investments in research and development and intensive R&D efforts, and advancing to commercialization and the establishment of firm market demand. In the fine-ceramics functional materials field also, it took some 20 or 30 years to firmly establish the industry. When we transfer this experience to the field of structural materials, where serious development work only got underway in the late 1970's, we may expect the industry to be firmly established sometime early in the 21st century.

<2> Development of Structural Materials

Development work on functional materials got under way rather early in Japan, and our history of product development in this field now spans about 40 years. Serious R&D in the field of structural materials, on the other hand, did not begin until instigated by the development of ceramic gas turbines in other countries following the first oil shock. Since the late 1970's, however, new materials has become--together with electronics and the bioindustry--a field in which major technological breakthroughs are expected. Many companies therefore jumped into the field of structural materials, hoping thereby either to bring some existing industry into the world of high-tech or to develop a new high-growth field (cf Table 1-1).

According to a survey conducted by the Ministry of International Trade and Industry (MITI) in March, 1989, approximately half of the companies who moved into the field of fine ceramics did so after 1980. We believe that almost all of these companies were interested in structural materials when they moved into the field of fine ceramics (cf Table 1-2).

Table 1-1 Reasons for Moving [Into Fine Ceramics]

Reason	Number of Companies
Market for existing products, materials stagnant	69
To upgrade existing products, materials	105
To keep competitive with other manufacturers	29
Needed for use in-house	36
Requested by product users	40
Hopes for high growth, high profits	102
Other	10

(168 companies responding, multiple answers allowed)
(Source: March, 1989, questionnaire survey of Ministry of International Trade and Industry (MITI))

Table 1-2 Period of Move [Into Fine Ceramics]

Prior to 1975	1975 - 1980	1981 - 1985	1986 - 1988	1989 -
36	14	30	10	11

(168 companies responding)
(Source: MITI questionnaire survey, March, 1989)

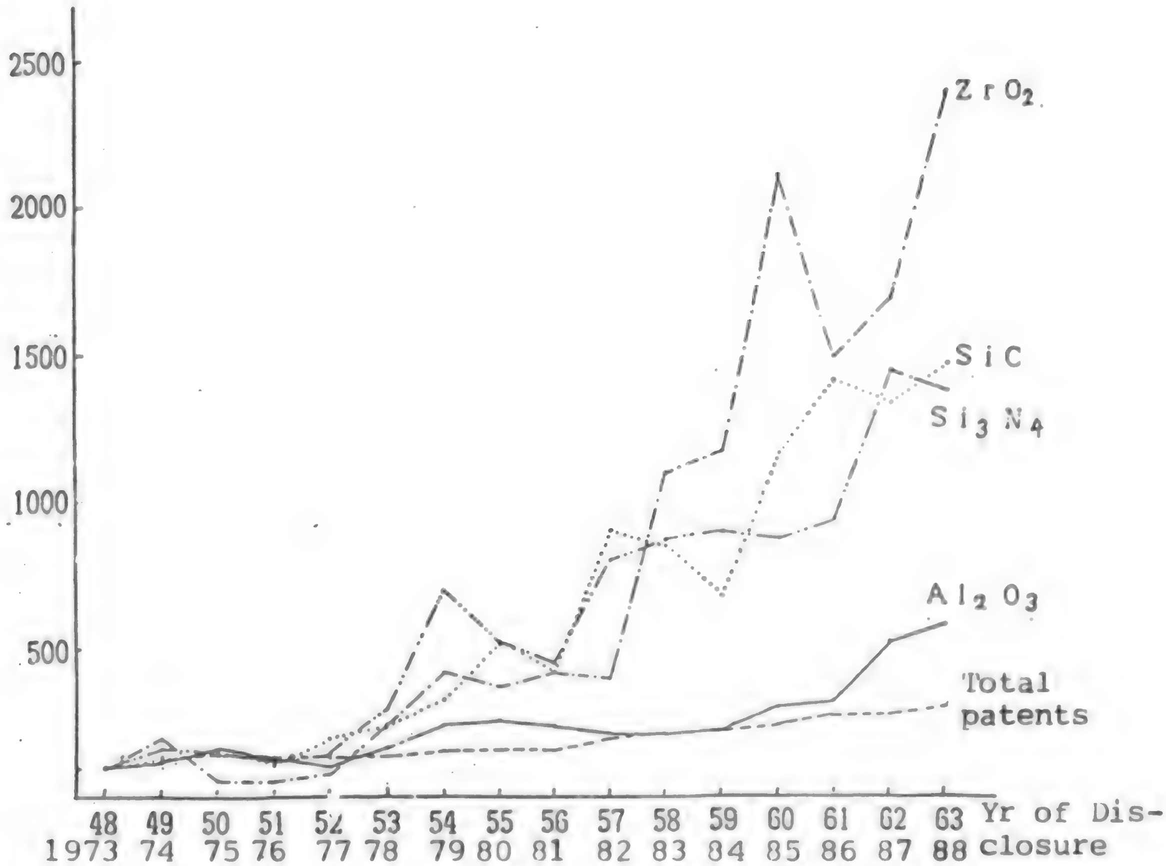
Also, the number of patent disclosures pertaining to such representative structural materials as silicon carbide (SiC), silicon nitride (Si_3N_4), and zirconium oxide (ZrO_2) (most of which is used as a structural material), have been increasing since 1975, and increasing very rapidly since 1980. This trend is indicative of the many companies which became seriously involved in this field in the late 70's and especially since 1980 (cf Figure 1-2).

Accordingly, whereas functional materials, with a 40-year history of development, are now in the growth stage, structural materials have only a short development history of little over a decade, and are still in the developmental stage, with the stages of expansion and growth still lying in the future.

(3) Fine Ceramics & Advances in Technological Development

It was not until the early 1980's that technological development got going in a big way in the field of structural materials. Technological development in Japan is now being promoted with an emphasis on structural materials. With the implementation of the R&D System for Next Generation Industries (the so-called "Next Generation System"), fine ceramics materials were

Figure 1-2 Patent Disclosure Index Trend (100 in 1973)

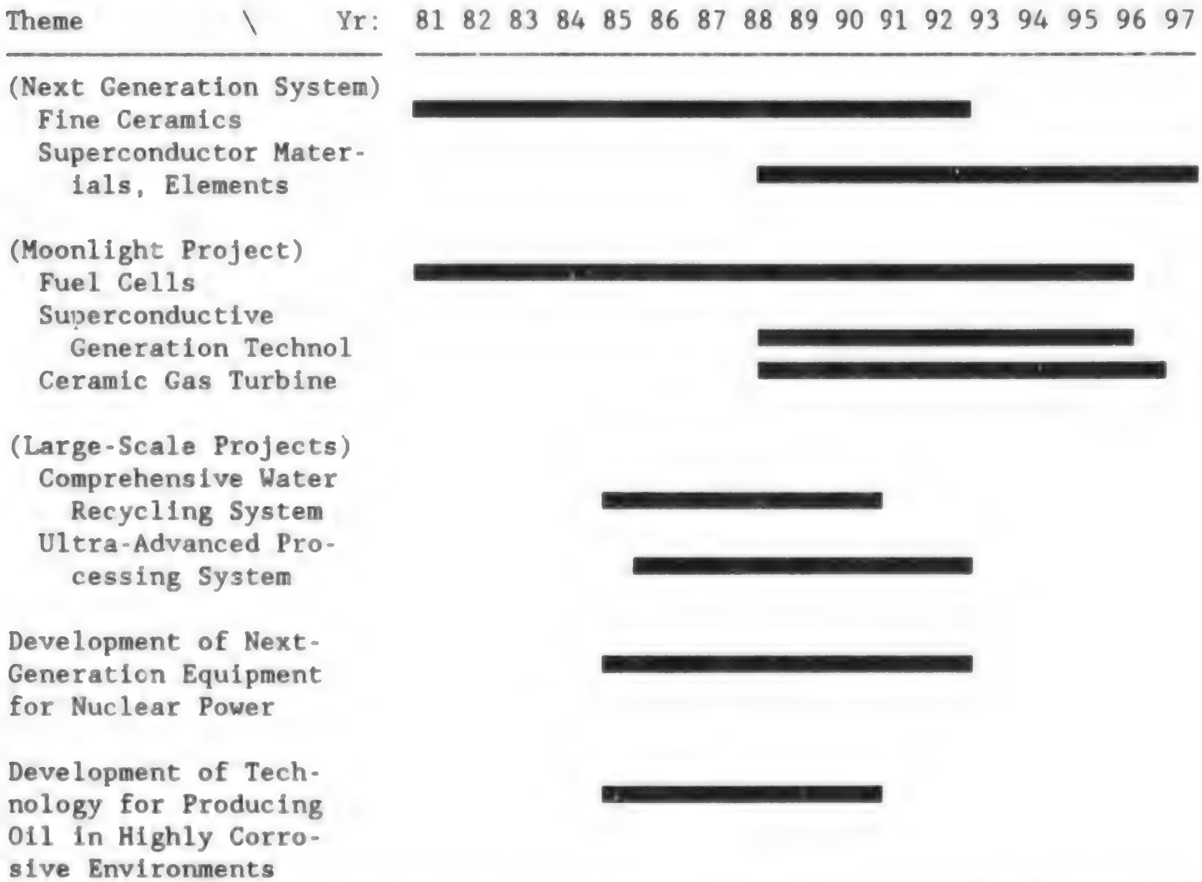


taken up as a theme first in 1981. From these beginnings, fine ceramics R&D is now being done in connection with various different projects (cf Table 1-3).

Concerning the benefits gained from domestic technological development, the gains made in materials development were incorporated into the development of ceramic components in the development of the ceramic gas turbine, and were shared among various projects. These gains also contributed greatly to the improvement of technological capabilities in the private sector, and even to the expansion of the fine ceramics industry.

Technological development is also going ahead full steam in private industry itself, spurred on by keen competition between companies. We wish now to look at how the gains made in this technological development are being put to use, and then consider automobile engine parts and tools.

Table 1-3   Fine Ceramics R&D Projects



Note: Fine ceramics R&D was also conducted in connection with the "high-efficiency gas turbine" segment of the now-completed Moonlight Project.

In the field of engine parts, much R&D has been done over a long period of time, including the development of silicon nitrides which excel in strength and heat resistance, techniques for joining fine ceramics and metals, precision molding techniques for fine ceramic materials, cutting and polishing processes, design optimizing techniques, and inspection methods suitable for mass production applications. These gains have resulted in the development of such fine-ceramic products as vortex chambers for diesel engines, turbocharger rotors, and rocker arm chips.

In the field of tools, the development of Thyalon [from phonetics] and silicon nitrides which excel in defect resistance and antiwear properties has resulted in the development of cast-iron milling tools which could not be made with conventional alumina materials. Techniques have also been perfected for coating titanium carbides and nitrides with chemical vapor

deposition (CVD), which have led to the development of high-speed cutting tools with improved antiwear properties. The demand for these tools is expected to continue growing.

1-2 Properties of Fine Ceramics

(1) Properties as Base Material

Fine ceramics may be defined as following (from May, 1984, report of Fine Ceramics Basic Issues Forum).

--Multipurpose inorganic materials, mainly having a microscopic structure in which many crystalline particles are bonded together, in which raw materials are used which have been refined and modified so as to maximize certain selected properties [lit. "functions"] from among those exhibited by ceramic materials, which have controlled chemical compositions, and in the manufacture of which the microscopic structure and morphology of the materials are controlled--

Fine ceramics exhibit a great variety of functional properties, depending on the raw materials used, the chemical composition selected, and the baking procedures and conditions used during manufacture. Morphologically, most fine ceramics are polycrystalline baked or sintered bodies, but others are monocrystalline, thin-film, or fiber materials, as the case may be.

Fine ceramics are used in many different applications, using different functional and morphological combinations. Their electromagnetic and optical functions are utilized in IC packages, capacitors, and other electronic and electrical devices and components. They are also used in optical fibers and other optical components. Their use as structural materials has recently been on the increase. And their biological and chemical functions are employed in artificial bone and in biological sensors (cf Appendix 2).

Japan is dependent on foreign imports for almost all of the raw material resources used in fine ceramics, but this poses no particular problem, at least for the present. As mass production expands in the future, however, measures will have to be taken to insure stable supplies of raw materials.

(2) Special Manufacturing Processes

Fine ceramic manufacturing processes include baking processes which demand sophisticated technology for precision control, as well as experience and much know-how. That is why growth in this field has been retarded, despite the outstanding properties of fine ceramic products. Typical fine-ceramics manufacturing processes include the process of manufacturing raw-material powder, molding processes, baking processes, and other fabricating processes. Also of great importance are the measuring and evaluating proce-

dures which must be conducted at each stage of the manufacturing process (cf Appendix 3).

The sub-processes involved in the manufacture of fine-ceramics raw-material powder generally include raw-material synthesis, crushing, sorting, and granulation. The characteristics of the raw-material powder have a great impact on the properties of the final finished product. Solid-phase methods have been conventionally employed in this process, but the need to obtain ultra-fine sub-micron powders of high purity has resulted in the development and industrialization of new raw-material synthesizing techniques such as vapor-phase and liquid-phase methods.

In the fine-ceramics molding processes, organic molding enhancers (called "binders") are used. Hence we may understand the molding processes as including the steps of raw-material processing and the removal of the binder from the green molded materials after molding, as well as the actual shaping processes. Die molding and rubber press molding are employed in the molding of simple shapes, while for the molding of thin sheet materials either extrusion molding or the doctor-blade method (a form of cast molding) is employed. Injection molding techniques are used for molding complex shapes. For the binder-removal process, it is important to examine the thermal decomposition properties of the organic material used and to carefully control temperature and pressure during the process.

For the baking of fine ceramic materials, normal-pressure baking techniques are most commonly used, although other baking methods are also used, depending on the composition and the finished product. These other methods include special atmosphere baking and reactive baking. Use is also now being made of the hot pressing method of baking under high pressure, and of the hot isostatic pressing (HIP) technique.

Due to the hardness and brittleness of the fine ceramic material after baking, chipping and cracking occur readily due to the mechanical and thermal forces encountered during processing. As a result, the processes used in manufacturing fine ceramic products often cause a deterioration in material strength or functional properties. Nevertheless, by doing the processing with great care, it is possible to satisfactorily employ the characteristics of fine ceramics, though better processing techniques still need to be developed.

(3) Characteristics of Fine Ceramics Industry

Fine ceramic materials constitute one category of new materials which are used mainly in advanced technological fields, just as are other new materials. How well producers in this field are able to cope with the extremely diverse demands of users and with technological breakthroughs is related to how successfully they beat the competition from other new materials and cultivate demand growth. Another peculiarity of fine ceramics is that,

compared to other new materials, the demand for them extends over a wide range of fields. This industry is being joined by many users who are seeking more sophistication and greater diversification in their products, and by many manufacturers in other fields who are seeking to develop new fields through the application of similar material manufacturing techniques. Two more aspects which are characteristic of fine ceramics are the regional and international dimensions. With respect to the regional dimension, we may understand the fine ceramics industry--broadly defined--as belonging to *yogyo*, that is, to the traditional ceramics industry which includes brick-making, glassmaking, and cement manufacture. This *yogyo* ceramics industry has traditionally been a regionally based industry, and at the present time many small companies and corporations involved in such regional ceramics operations wish to move into the field of fine ceramics. As to the international dimension, Japan's share of the worldwide production volume is extremely large, our technological level is high, and hence the Japanese fine ceramics industry is attracting intense attention internationally.

<1> Fine ceramics, as already noted, have a variety of outstanding material properties. As a result, fine ceramic products are employed in a very wide range of industrial and domestic applications. These include applications as functional materials in electronic components, applications as structural materials in automotive parts, applications as biological materials in artificial bones, and use in everyday items like knives and scissors. Whereas conventional materials were employed in a rather limited range of applications, by a narrow segment of users, fine ceramic materials are being demanded in unprecedented applications, and producers are obliged to investigate the diversified needs of people whom they have never come into contact with before, including people in industrial, biological, medical, and general consumer fields.

<2> Multiple-Model, Small-Lot Production

It is currently necessary to employ a baking or sintering process in order to give final shape to a fine ceramics product. Unlike with other materials, therefore, manufacturers are being pressed by extremely detailed user demands for component-based production operations, requiring the manufacture of very many different models of a product. And the recent trend toward greater diversification of user demand is putting even more pressure on producers to provide their fine ceramics products in a greater variety of models. Not only are greater functionality and higher performance demanded in the products, but smaller, lighter products are being demanded (particularly in the field of electronics equipment). As a result, while overall production volumes are rising, production lots for each specific product are becoming smaller. These demands for multiple-model, small-lot production tend to require more production process changeovers and greater numbers of molds and dies, and hence result in higher costs. Thus fine ceramics producers need to carefully manage their production operations so that they can most efficiently implement multiple-model, small-lot production.

<3> Merging Diverse Industries

Those companies moving into the fine ceramics industry include--in addition to those representing the traditional ceramics industries--companies engaged primarily in steelmaking, non-ferrous metals, chemicals, fibers, other materials, electrical and electronic equipment, transportation equipment, process and assembly, engineering, manufacturing equipment, measuring equipment, and various other equipment and systems manufacture. As a consequence, technology is being formed in the fine ceramics industry, and its use is being widely spread, as to conventional ceramics technology are added elements from process technologies used by manufacturers of other materials, application technology developed by users, and manufacturing equipment technology. This merging of such diverse connections and industries is likely to promote greater information exchange, research and development, and product development in the future.

From the results of the questionnaire survey conducted by MITI, we know that the greatest number of industry types are moving into the field of inorganic new materials (of which fine ceramics is the primary member), more, that is, than into other fields such as polymer- or metal-based new materials. Most companies who are moving into polymer- or metal-based new materials are either chemical or textile companies which formerly got into polymer materials and have now moved into polymer-based new materials, or steel or non-ferrous metal companies which formerly got into metallic materials and are have now moved into metal-based new materials. These companies are

Table 1-4 Trends in New Materials Products by Industry

Industry	Number of Companies	Number of Products, by Material					Total
		Organic	Inorgan	Metal	Compos	Raw Mater	
Chemicals	15	164 (47.1)	97 (27.9)	16	45 (12.9)	26	348 (100)
Textiles (Fibers)	7	109 (75.1)	11 (7.6)	2	21 (14.5)	2	145 (100)
Non-Ferrous Metals	11	14	63 (43.8)	44 (30.6)	18 (12.5)	5	144 (100)
Steel	15	3	30 (22.7)	75 (56.8)	16 (12.2)	8	132 (100)
Glass, Earth & Rock	12	13 (10.9)	73 (61.3)	2	16 (13.4)	15	119 (100)

Share, by material, noted as percentage in parentheses ( ).
(Source: MITI questionnaire survey, July, 1988)

capitalizing on existing materials technologies to commercialize products in these fields. Most of the diverse industries moving into new materials are in fact moving into fine ceramics (cf Table 1-4).

<4> Short Life Cycle

The development history for such functional fine ceramic products as electronic components is relatively long, and the material properties of fine ceramics are well exploited in these products. Technological breakthroughs are being made very frequently by the electronic equipment makers who constitute the users of these products, however, and there are price and performance pressures from competing materials. Hence the life cycle for fine ceramic products tends inevitably to be short. This in turn necessitates a never-ending cycle of successive development efforts. Structural fine ceramics are still in the developmental stage, moreover, and their performance parameters are expected to be greatly improved in the future as further advances are made in technology. These higher-performance materials will lead to the development of many new products and improvements in existing products, and the life cycle of these structural fine ceramics will also be very short.

<5> Activities of Small, Regionally Based Companies

The fine ceramics industry has developed out of the traditional *yogyo* ceramics industry. Although the materials used and the properties and applications of products are very different from traditional (classic) ceramics products, fine ceramics does employ baking processes and hence can be included within the *yogyo* field. This being so, we already see small and medium companies moving from traditional ceramic fields into the fine ceramic field. Most small and medium companies now engaged in regional ceramic (*yogyo*) operations wish to move into fine ceramics. At present, however, such a move may be difficult due to limited capital and technological resources. Many traditional ceramics operations have the characteristics of regional businesses. In the interest of promoting regional industry, however, it is desirable that such regionally based companies become more prosperous.

<6> International Interest

Japan's fine ceramics industry enjoys a dominant position in the world market, particularly in the area of such electronics components as IC packages. R&D work in structural materials is also very active. According to the assessments made by domestic observers, Japan's technological level, especially in the area of manufacturing technology, is unsurpassed in the world. Other nations have directed their attention to Japan's capital and informational resources, and Japan is being asked to cooperate with other countries of the world in developing testing and evaluation techniques and building databases.

(4) Developing Toward 21st Century

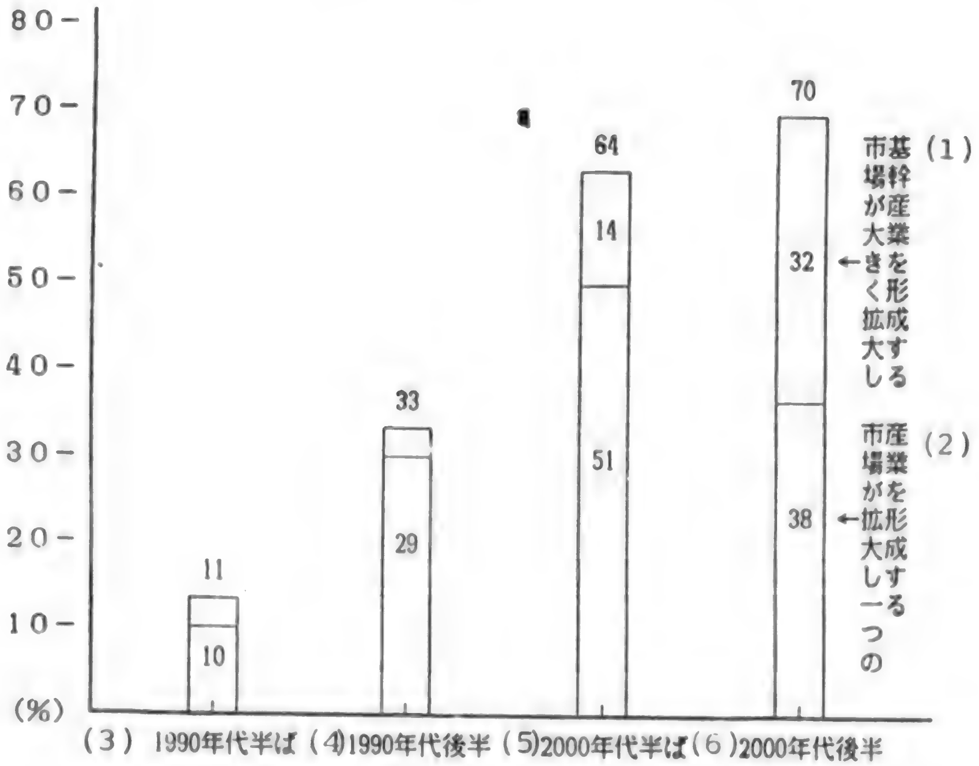
Progress in such advanced industrial fields as data communications, aerospace, and the life sciences is of course dependent on system development, but it is also dependent on the development of the element technologies from which systems are made up and ultimately on the development of materials. In many cases, looking at it from the opposite perspective, it is extremely difficult to configure new element technologies and systems without first developing the underlying materials.

Greater heat resistance, corrosion resistance, and radiation resistance are now needed in materials, and there are demands for structural materials which can withstand harsh environments that are utterly destructive of conventional materials, as well as for functional materials which have diverse chemical, optical, and electromagnetic functional properties. Fine ceramics are very important materials, and they are expected to meet the challenge of these rigorous and diverse demands. It is believed that these materials will provide foundational support for various industries that will flourish as we approach the 21st century. That is why they are being watched with such interest.

It is possible that fine ceramics may be used in practically implementing gas turbines for use in automobiles as well as in electrical power generation, thus leading to improved energy utilization efficiency. The resulting conservation of energy resources may in turn help to protect our global environment. The nickel, chromium, cobalt, and other rare metals now used in heat-resistant alloys are available from only a few producer nations, and their continued stable supply cannot be taken for granted. If greater use can be made of silicon carbide and silicon nitride as substitutes for rare metals, this again will contribute to the conservation of our natural resources.

The fine ceramics industry may not as yet be a foundational industry in the world economy, but by the middle of the first decade in the 21st century it will either "constitute an industry with expanding markets" or "constitute a foundational industry with greatly expanding markets." That is the view of most companies polled in a questionnaire survey conducted in March of this year by the Ministry of International Trade and Industry (cf Figure 1-3). We believe that, as we move into the 21st century, the markets for fine ceramics will expand greatly, and that it will become a foundational industry in the new century.

Figure 1 - 3   Fine Ceramics Industry Projections



(311 companies responding) (Source: MITI survey, March, 1989)

Key:

1. Markets will expand greatly; will constitute foundational industry
2. Markets will expand; will constitute [a viable] industry
3. Mid-1990's
4. Late 1990's
5. Mid-2000's
6. Late 2000's

Chapter 2   Fine Ceramics Industry Today

2-1   Fine Ceramics Production & Development Today

(1)   Fine Ceramics Business

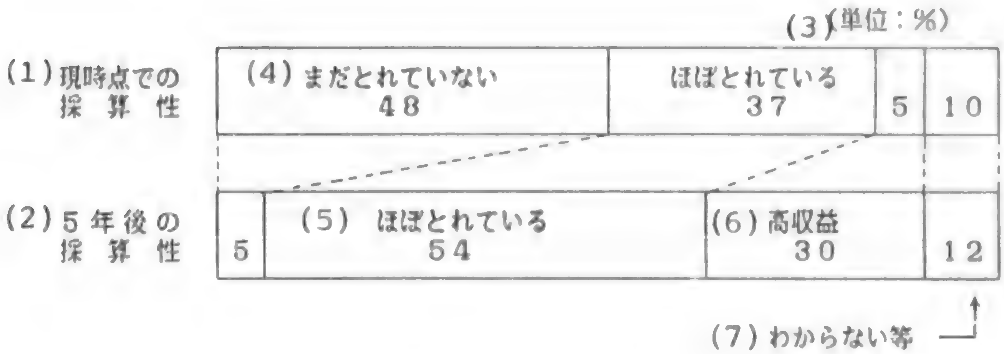
In the fine ceramics industry, only a few companies which moved early into the field of functional materials--which is now in its growth stage--are generating high earnings. Most of these companies are making structural

materials--still in the development stage--their main business interest. As a consequence, production volumes are low, and profits are not too good.

According to the questionnaire survey conducted by the Ministry of International Trade and Industry (MITI) in March of this year, roughly half of the companies polled say they are "still not making a profit" in this business, and only 5 percent report generating "large earnings" (cf Figure 2-1). About half of these companies say they expect this business to be "more or less profitable" within 5 years time, and roughly 30 percent expect to generate "large earnings" within that time frame. There are thus expectations that this business will become viable at an early stage. At the present time, "less than 5 percent" of the companies polled report that fine ceramics sales currently account for 70 percent [or more] of total sales, while "more than 5 percent" of them expect this ratio to be 60 percent [or more] within 5 years time. Thus the fine ceramics business is expected to constitute a larger share of the overall business.

Looking next at fine ceramics production trends by application (Figure 2-3), we see that most production is geared toward thermally, mechanically, and electromagnetically functional materials. Comparing these results with those of a survey made 5 years ago, we see that the greatest growth has been in electromagnetically functional materials, although growth in thermally and mechanically functional materials has also been very good.

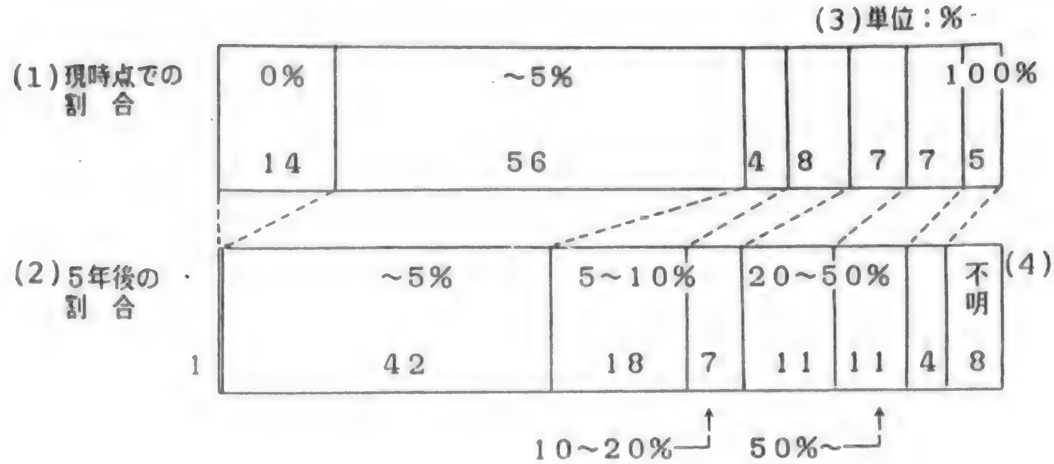
Figure 2-1 Profitability of Fine Ceramics Business
(311 companies responding) (MITI survey of March, 1989)



Key:

1. Current profitability
2. Profitability 5 years from now
3. (Units = %)
4. Not yet profitable
5. More or less profitable
6. High earnings
7. Don't know, other

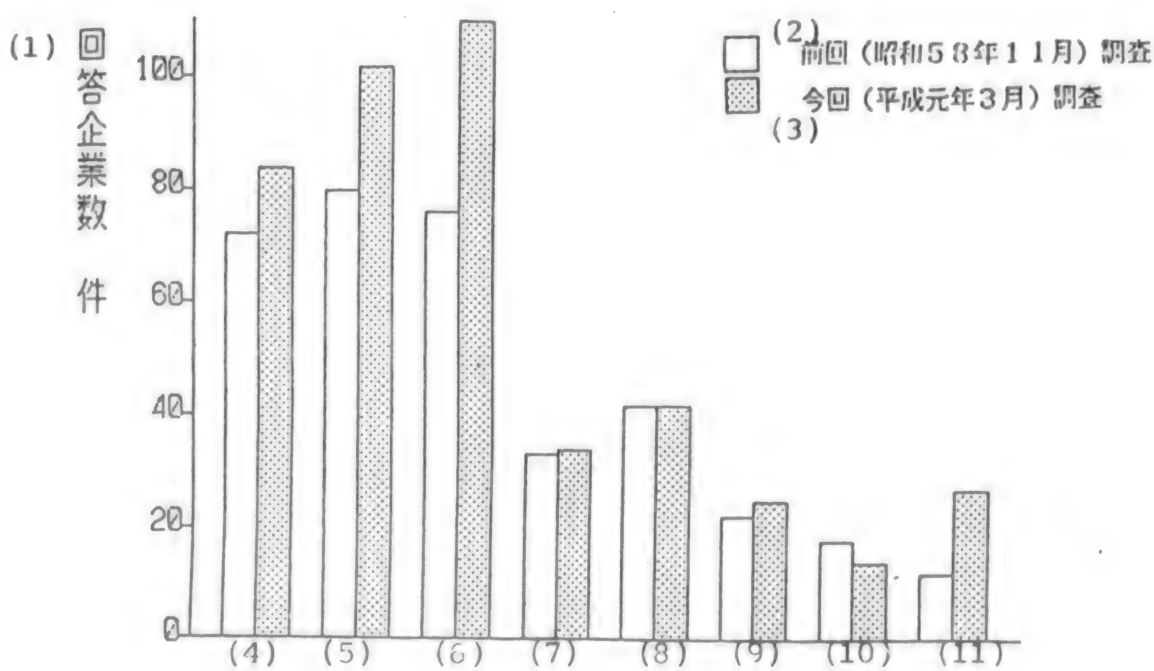
Figure 2-2   Fine Ceramics Share in Total Sales
(194 respondents) (MITI survey of March, 1989)



Key:

1. Current share
2. Units = %
2. Share 5 years from now
4. Unknown

Figure 2-3   Production Trends for Functional Materials
(194 respondents) (MITI survey of March, 1989)



Key to Figure 2-3:

1. Number of companies
2. Previous survey (November, 1983)
2. This survey (March, 1989)
4. Produce thermally functional materials
5. Produce mechanically functional materials
6. Produce electromagnetically functional materials
7. Produce optically functional materials
8. Produce chemically functional materials
9. Produce biologically functional materials
10. Produce functional materials related to nuclear power
11. Produce other functional materials

(2) Fine Ceramics Production

The scale of the fine ceramics market is represented in Table 2-1. This table is based on the results of MITI's "Production Statistics" and a production trend survey conducted by the Japan Fine Ceramics Association.

The size of the market has definitely been growing over the past few years, and it reached 1.15 trillion yen in 1987 (including synthetic diamonds). Looking at the breakdown of fine ceramics applications in 1987, excluding synthetic diamonds, we see that electromagnetic applications account for a whopping 70 percent or so. The approximate growth rates from 1985 to 1987 (i.e. 1987/1985) were 1.1 for electromagnetic applications, 1.0 for medical applications, 1.3 for machine applications (excluding tools), and 2.0 for thermal applications. Hence structural materials exhibited greater growth than functional materials, and this trend is expected to continue as more experience is gained in using such structural materials.

<1> Electromagnetic Applications

The major products in this category are IC boards and packages, thermistors, varistors, compound semiconductors, magnetic materials, capacitors, piezo-electric elements, crystal oscillators, and spark plugs. This growth has expanded rapidly along with the growth of the electric/electronics industry. Production reached approximately 740 billion yen in 1987, of which IC boards and packages accounted for about 136 billion yen, magnetic materials for roughly 150 billion yen, and capacitors for another 180 billion yen or so.

<2> Tool, Machine Applications

The major products in this category include superhard materials such as WC (work center) tools, ceramic tools, molds, and dies, and antiwear materials for abrasion-resistant liners, mechanical seals, rollers, and bearings. Overall production reached approximately 100 billion yen in 1987. Of this,

Table 2-1 Production of Fine Ceramics Materials

(1)単位：億円 (%)

(15) 年 ＼ (2) 用途	(3) 電磁気	(4) 工具・機械	(5) 工具	(6) 機械	(7) 光学	(8) 化学・医療	(9) 熱	(10) その他	(11) 小計	(12) 前年比	(13) ニューダイヤモンド	(14) 合計
(16) 昭和60年	6,720 (70.4)	1,070 (11.2)	840 (8.8)	230 (2.4)	680 (7.1)	600 (6.3)	250 (2.6)	220 (2.3)	9,540 (100)	——	800	10,340
(17) 昭和61年	6,920 (69.8)	960 (9.7)	710 (7.2)	250 (2.5)	850 (8.6)	600 (6.0)	380 (3.8)	210 (2.1)	9,920 (100)	104.0	820	10,740
(18) 昭和62年	7,400 (69.5)	1,000 (9.4)	690 (6.5)	310 (2.9)	920 (8.6)	620 (5.8)	500 (4.7)	200 (1.9)	10,640 (100)	107.3	820	11,460
(19) 昭和63年 (見込み)	8,370 (70.5)	1,150 (9.7)	770 (6.5)	380 (3.2)	890 (7.5)	660 (5.6)	610 (5.1)	200 (1.7)	11,880 (100)	111.7	920	12,800

(20)(通商産業省生産動態統計、(社)日本ファインセラミックス協会調査等により作成)

Key to Table 2-1:

1.	Units: 100 million yen (%)	2.	Use, application
3.	Electromagnetism	4.	Tools, machines
5.	Tools	6.	Machines
7.	Optics	8.	Chemicals, medicine
9.	Heat	10.	Other
11.	Subtotal	12.	Percentage of previous year
13.	Synthetic diamonds	14.	Total
15.	Year	16.	1985
17.	1986	18.	1987
19.	1988 (projected)		
20.	(Based on MITI Production Statistics, survey conducted by Japan Fine Ceramics Association)		

tool and other superhard materials have a longer history than do other structural materials, so demand reached a somewhat large 69 billion yen or so. This is affected by the relative prosperity of the users, however, for which reason this market has been sluggish for the past several years. The production volume of antiwear materials and other machine materials reached roughly 31 billion yen, up 24 percent from the previous year, which represents a growth rate that is well above the average.

<3> Optical Applications

The major products in this category include optical fibers, optical-fiber connectors, and photomasks. The bulk of this market is in optical fibers. Production in 1987 amounted to roughly 92 billion yen. This is a relatively new field, but it is already developing a stable market.

<4> Chemical, Medical Applications

The major products in this category include sensor elements for oxygen, gas, and humidity sensors, catalysts and catalyst vehicles, and artificial teeth, bone, joints and other prosthetic materials. Overall production reached approximately 62 billion yen in 1987, of which roughly 17 billion yen was accounted for by oxygen sensor elements, 39 billion yen by catalysts and catalyst vehicles, and 3 billion yen by prosthetic materials. Rapid growth is being seen in the various sensor and prosthetic material fields.

<5> Thermal Applications

The main products in this category include engine parts such as turbocharger rotors and hot plugs, and high-temperature anticorrosive materials for nozzles and crucibles. Production was approximately 50 billion yen in 1987, up 32 percent from the previous year. This field has been growing rapidly over the past few years, just as has the field of machine applications.

Research and development in this field is very active in both government and private institutions. The gains from this R&D are expected to translate into demand growth, enhanced reliability, and cost reductions, resulting in the development of a large market.

<6> Other

The major products in this catch-all category are materials related to nuclear power, and consumer- or culture-oriented products. Production reached roughly 20 billion yen in 1987. The market for nuclear-power products is now extremely small, but demand is expected to grow in the future.

<7> Synthetic Diamonds

Synthetic diamond production in 1987 was about 82 billion yen, with most of these diamonds being used in industrial tool applications. In recent years, thin-film diamonds have been synthesized in conjunction with the advent of vapor-phase synthesizing techniques, and these diamonds are used in such audio products as speaker sounding boards, and in heat sinks. These applications are expected to expand in the future, and a new application as an anti-abrasive material for magnetic recorder heads is being developed.

(3) Research & Development

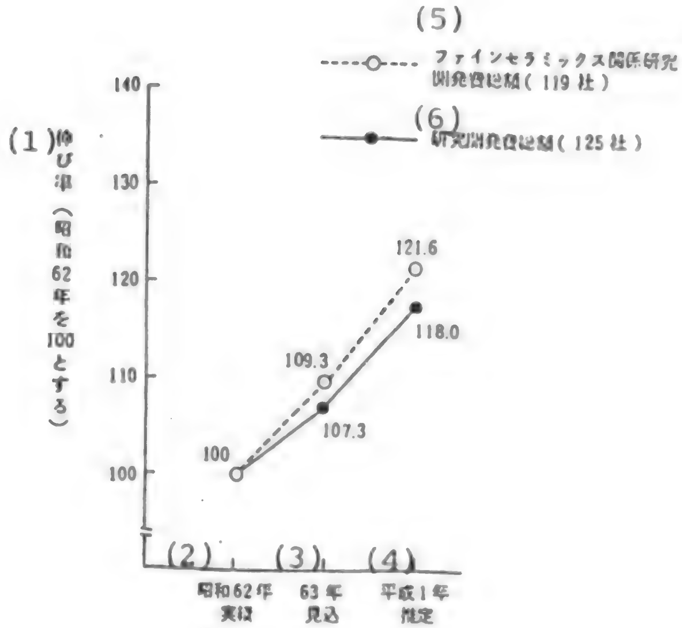
<1> Trends in Research Expenditures, Research Personnel

The growth in R&D expenditures and numbers of research personnel in the fine ceramics field in private industry are plotted in Figures 2-4 and 2-5. The growth in R&D expenditures for fine ceramics is higher than the growth in overall R&D expenditures, as is the increase in research personnel over the growth of employee numbers in general. These trends are indicative of the priority being given to fine ceramics research.

As we see in Figure 2-6, 54 percent of the companies surveyed report that fine ceramics R&D expenditure accounts for less than 5 percent of total research expenditures. However, more than 70 percent of these companies predict this ratio to be 5 percent or greater within 5 years time. Thus R&D expenditure is expected to exhibit large growth in the future.

Examining the ratio of fine ceramics research personnel to total research personnel (Figure 2-7), we see a very similar trend to that indicated by present and predicted research expenditure. Many companies predict increased growth within 5 years time.

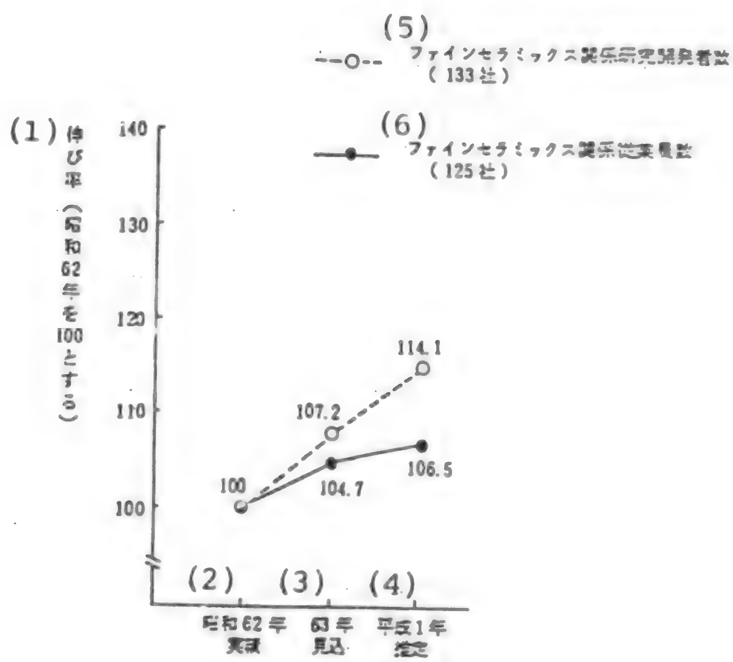
Figure 2-4 Fine Ceramics Research Expenditure & Total Research Expenditure (Source: 1988 Survey of Fine Ceramics Industry Trends by Japan Fine Ceramics Association)



Key:

1. Growth rate (1987 = 100)
2. 1987, actual
3. 1988, projected
4. 1989, estimated
5. Total fine ceramics related R&D expenditure (119 companies)
6. Total R&D expenditure (125 companies)

Figure 2-5 Personnel Engaged in Fine Ceramics & General R&D Personnel
(Source: 1988 Survey of Fine Ceramics Industry Trends by Japan Fine Ceramics Association)



Key:

1. Growth rate (1987 = 100)
2. 1987, actual
3. 1988, projected
4. 1989, estimated
5. Employees engaged in fine ceramics R&D
6. Total employees engaged in R&D

Figure 2-6 Present & Predicted R&D Expenditure in Fine Ceramics Industry
(194 respondents) (MITI survey, March, 1989)

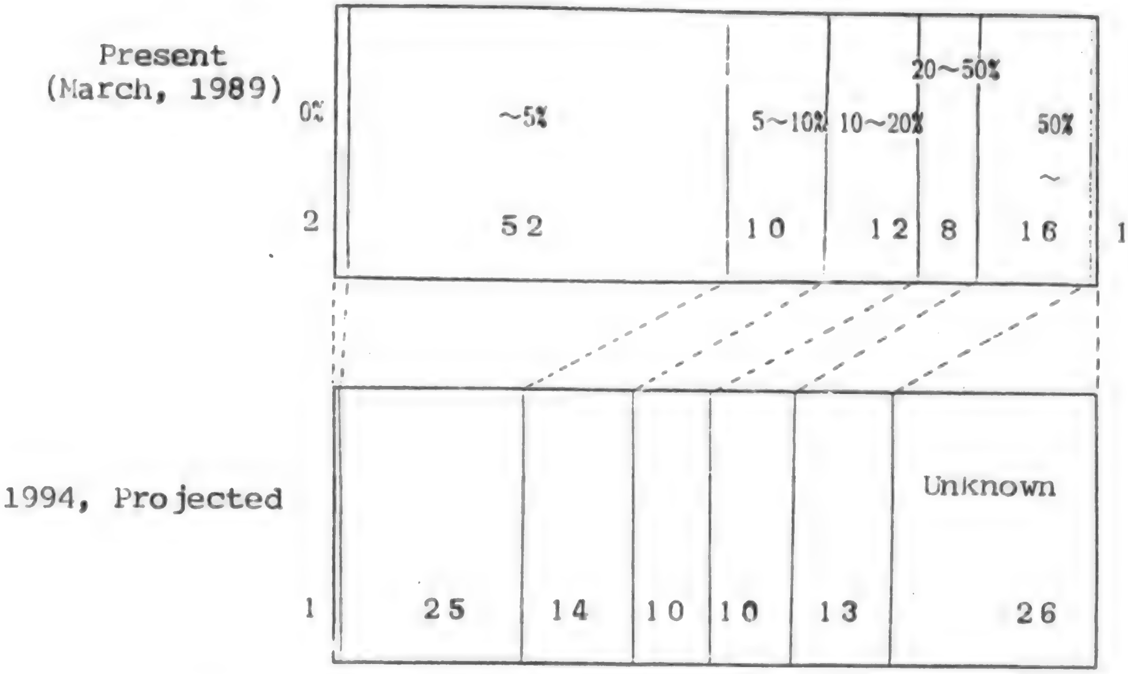
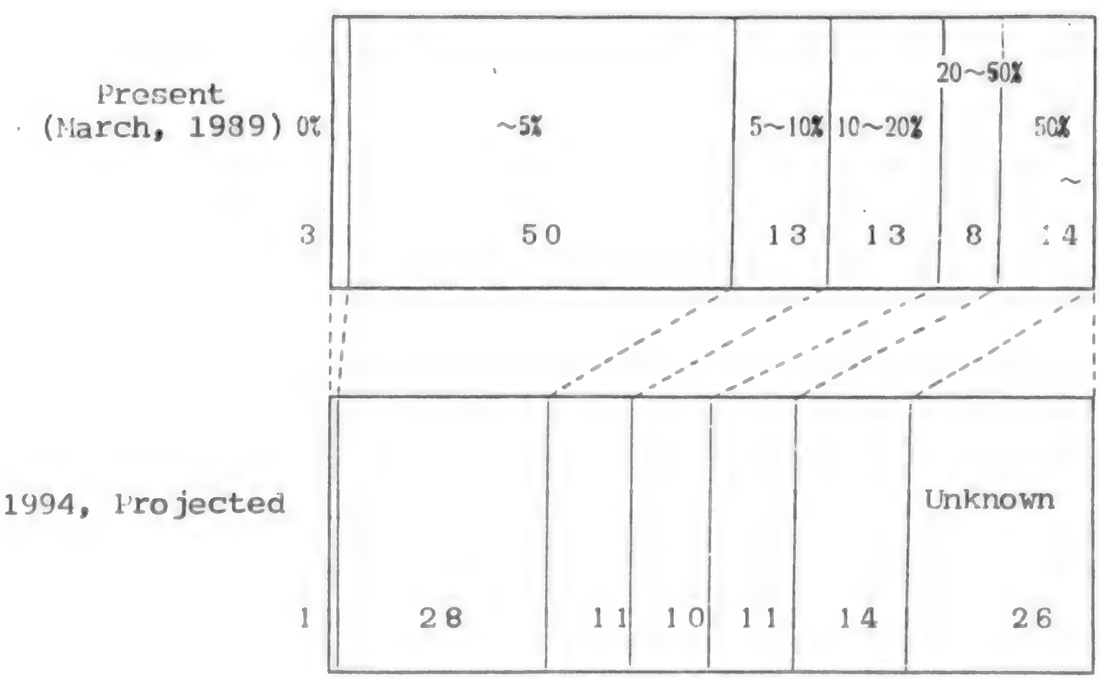


Figure 2-7 Fine Ceramics Research Personnel--Present & Predicted
(194 respondents) (MITI survey, March, 1989)



<2> Recent R&D in Terms of Patent Trends

Whereas the growth rate for numbers of patents disclosed during the late 1970's was nearly constant, the growth rate for patents pertaining to fine ceramics materials, in general, rose very significantly, particularly in the early 1980's, and patent filings in this field continue to be very numerous.

Looking at patent disclosures over the past 5 years, we see very avid R&D activity in the structural materials field, with most of the patents pertaining to zirconia (ZrO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and alumina (Al_2O_3). R&D activity is also very intense in the functional materials field, particularly in research related to electronic materials. Many patents in this field relate to such oxides as titania (TiO_2), alumina, and perovskite (cf Table 2-2).

Table 2-2 Materials Frequently Patented Over Past 5 Years

Rank	Material	Patents in 5 Years
1	TiO_2	671
2	Al_2O_3	549
3	ZrO_2	491
4	SiC	468
5	Si_3N_4	447
6	$Pb(A_xB_y)O_3$, etc	397
7	PZT	213
8	AlN	212
9	ZnO-based	144
10	BN	114

(1984 - 1988)

Japan, by the way, lags behind the United States in research and development in the field of composite materials.

<3> Fine Ceramics R&D in Japan

In Japan, R&D on fine ceramics materials and systems is moving ahead in the context of various projects and programs, and at government testing and research facilities (cf Appendix 4).

Looking next at the share of total patent disclosures over the past 5 years accounted for by different materials, we see that the most actively patented materials are such new functional materials as aluminum nitride (AlN), which shows promise as an electronics substrate material, and phosphates for use as bioceramic materials; and such structural materials as zirconia, silicon

carbide, and silicon nitride. R&D work has recently become very intense in these areas (cf Table 2-3).

Table 2-3 Materials More Frequently Patented Over Past 5 Years

Rank	Material	Patents in 5 Years (%)
1	AlN	74
2	Phosphates	66
3	ZrO_2	61
4	SiC	43
5	Si_3N_4	41
6	$Pb(A_xB_y)O_3$, etc	38
7	Thyalon	36
8	Al_2O_3	35
9	Borides	34
10	Carbides	34

(1984 - 1988)

$$\frac{\text{(No of patent disclosures in past 5 yrs)}}{\text{(No of patent disclosures to date)}} \times 100$$

We will now give thumbnail sketches of the major national projects.

A. Fine Ceramics (Next Generation System)

The fine ceramics being developed in this project are structural materials which exhibit such characteristics as high-temperature strength, exceptional anticorrosive properties, and high wear-resistance. These materials are being developed for ceramic turbine components used in coal gasification. (Research period: 1981 - 1992; total R&D expenditure: approx 13 billion yen)

B. Ceramic Gas Turbine (Moonlight Project)

A 300-kW class ceramic gas turbine is being developed for cogeneration power facilities designed to conserve energy. (Research period: 1988 - 1996; total R&D expenditure: approx 16 billion yen)

C. High-Temperature Superconductor Ceramics Project (Next Generation System, Moonlight Project)

1) Superconductors, Superconductor Elements (Next Generation System)

By evaluating the physical properties of superconductive substances, this project aims to elucidate the structure of superconductors and discover substances which will maintain the superconducting state even under conditions of high temperature, high electric current, and strong magnetic fields. In addition, design and manufacturing process

technologies are being developed in the interest of even greater performance enhancement. Also under development are new manufacturing processes for implementing superconductors in thin-film and polycrystalline forms. In the field of superconductor elements, elements such as the superconductor transistor--which are only achievable with the use of superconducting materials--are being developed. In this connection, ultrafine processing techniques and other element technologies are under development also. (Research period: 1988 - 1977; total R&D expenditure: approx 25 billion yen)

2) Superconducting Power Generation Technology (Moonlight Project)

In this project, a superconducting electric generator and other superconducting power generation equipment are being developed. As electric power generation facilities become larger and larger, and as they are located more and more remotely from demand centers, problems related to building sites and power transmission loss are becoming very serious. The superconducting power equipment is being developed for the ultimate purpose of making electric power systems more efficient and stable. (Research period: 1988 - 1995; total R&D expenditure: approx 25 billion yen)

In addition to the projects outlined above, there are ongoing projects for developing advanced materials for extremely adverse environments and next-generation equipment for nuclear power generation. There are also 23 special research themes related to fine ceramics which are being pursued in testing and research facilities under the auspices of the Agency of Industrial Science & Technology. These "themes" are important research undertakings, although smaller in scale than the [national] "projects." They do not include research work commissioned to private research facilities.

(4) Cooperation Between Industry, Academia, Government

Fine ceramics are new materials. The demands for materials are becoming increasingly sophisticated. For this reason, R&D in such basic research fields as physical property theory and materials design will have to be done cooperatively between the fine ceramics industry, government, academia, and other industries, at university and national laboratories.

Joint development efforts will be essential, moreover, with machine manufacturers in developing new manufacturing processes, and with electronics, machine, and automobile manufacturers in developing new products. In the fine ceramics field--due to the peculiarities of the processes--molding, baking, and other processing are usually all worked out together with the material manufacturer, then the parts are shaped and sold to the user. Accordingly, the material itself goes into the distribution stream, and the fine ceramics producer must work more closely with the user in processing and making the final components than is the usual case between producer and user.

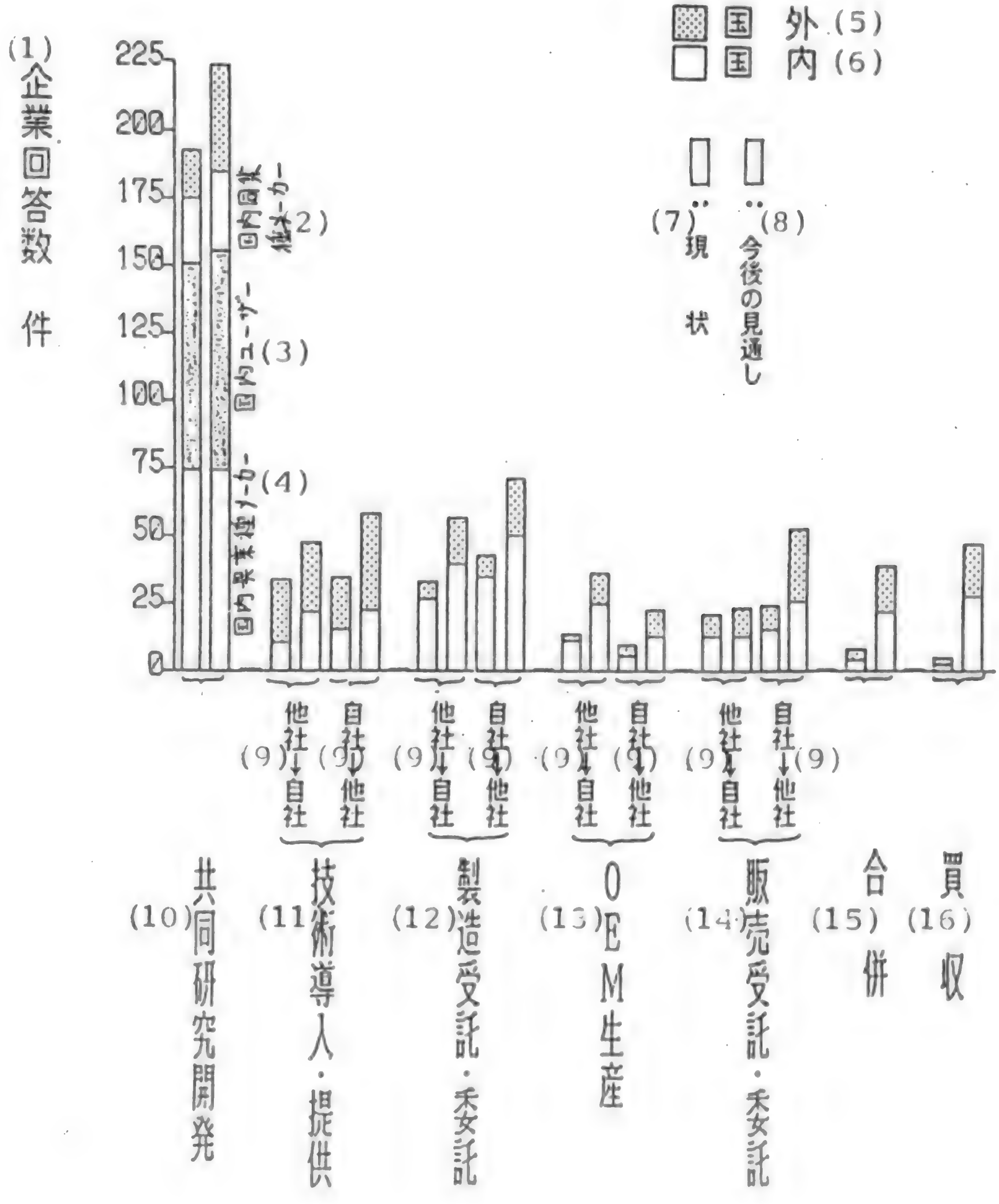
According to a questionnaire survey conducted by MITI (cf Figure 2-8), joint R&D is being conducted most actively between different companies. This cooperation is frequently between producers in different industries or between the producer and the user. These facts back up the views expressed above. All of the various modes of cooperation--joint R&D, technology transfers, commissioned manufacture, OEM production, and commissioned sales--are expected to increase as time goes on. It is also predicted that there will be some major changes in direction, such as a rapid increase in the numbers of mergers and takeovers (M&A)--already a frequent occurrence in Japan--and an enormous increase in tie-ups with foreign companies, reflective of how rapidly the fine ceramics industry is expanding internationally.

Finally, in Appendix 5 will be found newspaper articles describing, from the media perspective, the status of industrial cooperation in this field. From these articles one may see how business growth and R&D are being promoted by this diverse cooperation between industry, academia, and government. Particularly numerous are the cases of joint automotive-related development between different manufacturers, and the cases of joint development between universities and producers in the field of biological and orthopedic materials.

(5) From R&D Stage to Practical Implementation

As advances are made in research and development, utilization is gradually expanding. In March of this year, MITI conducted a questionnaire survey of users to determine how they are currently using--and how they plan in the future to use--fine ceramics components (cf Table 2-4). According to the results of this survey, some 250 components are now being used, with an

Figure 2-8 Cooperation Between Companies--Present & Future
(311 respondents; multiple answers allowed)
(Source: MITI questionnaire survey, March, 1989)



Key to Figure 2-8:

1. Number of companies so answering
2. Domestic companies in same industry
3. Domestic users
4. Domestic companies in different industries
5. Foreign
6. Domestic
7. Current status
8. Future projection
9. Other company → own company
10. Joint research & development
11. Technology transfer
12. Commissioned manufacture
13. OEM production
14. Commissioned sales
15. Mergers
16. Acquisitions

additional 124 items planned to be used. Hence it can be projected that new products will be used in many fields in the future. As this survey indicates, production volumes are not large at this time, but such so-called structural materials as thermal-system and machine components already make up about 57 percent of the items now in use. Looking at the number of items scheduled for use in the future, about 75 percent of these involve structural materials, with the ratio of those involving electromagnetic materials declining to 13 percent from 22 percent currently. These figures suggest that the results of the R&D which has recently been so vigorously conducted in structural materials are steadily leading to practical applications. On a field-by-field basis, there is rapid growth in the relative numbers of heat-related components used in engines and other machines.

Looking next at each field in turn, in the field of electromagnetic materials, we see such examples of progress as the high-heat-conducting substrates typified by low-temperature baked substrates and aluminum nitride, by laminated capacitors which are smaller and larger in capacity, and by practical implementations of piezoelectric actuator materials. In the field of thermal-system and machine materials, the emphasis is on heat resistance, wear resistance, and light weight in such components as turbocharger rotors and valves, other engine parts, heat exchangers, nozzles, and pumps. In the fields of chemical and medical materials, new applications are being made in artificial bones and teeth using the physiological compatibility of apatite hydroxide.

(6) Identifying Each Company's Strategy

As we saw in the previous section, the fine ceramics industry has progressed from the stage of giving priority to R&D to the stages of practical implementation and market expansion. This transition to the stage of product development makes it necessary, however, to expend more personnel and capital resources in basic research and materials development in order to respond to the increasingly exacting demands of users for higher quality and

Table 2-4 Fine Ceramics Materials--Current & Planned Applications

Function	Current Use		Use in Near Future	
Electromagnetic materials	56	(22.4)	16	(12.9)
Mechanical materials	109	(43.6)	50	(40.3)
Thermal materials	58	(23.2)	43	(34.6)
Optical materials	4	(1.6)	3	(2.4)
Chemical, medical materials	16	(6.4)	11	(8.9)
Other functions	7	(2.8)	1	(0.8)
Total	250	(100)	124	(100)

lower cost. It is also very difficult for any one company to respond to the entire spectrum of diverse needs in the marketplace, and there is a trend for each company to focus its technological prowess and exploit its potential in specific fields where it offers competitive and discriminating product . We may thus conclude that the strategies of each company will become clearly identifiable as demand increases.

Take for example the field of high-temperature, high-strength materials for ceramic gas turbines, which is a structural-material field. Large demand growth is projected for this field, but it will demand enormously expensive long-term development, making it difficult for every fine-ceramics producer to undertake such development. For this reason, many companies are focusing their efforts in this field on machine parts and other highly wear-resistent materials. Many companies have also combined their development work on structural materials with R&D work in the field of functional materials. In the functional-material field, implementation is already considerably advanced. This field also has a shorter product-life cycle than does structural materials. If an outstanding product is developed, therefore, it can be marketed as a new product or as a replacement for an existing product. At the present time, many companies--including those which do not produce a main product line--are implementing measures to ascertain user needs, develop seed technologies, and deploy market strategies, while targeting specific areas based on their own seed technologies. Some of the general electronics companies have user groups right within their own organization, so they are able to work closely with these groups in-house in developing products and promoting demand growth.

Some companies have been engaged in overseas operations for years in order better to develop sales channels for functional materials. These overseas operations have recently (since 1986) been increasing sharply, particularly in North America, Western Europe, the Republic of Korea, Taiwan, and various member nations of ASEAN. Many companies have plans to set up operations overseas. The reason in roughly a third of these cases is to expand sales

channels (cf Tables 2-5, 2-6). Other factors are the strong yen, abundant labor supply, and avoidance of trade friction.

Table 2-5 Overseas Expansion (Current & Scheduled)--Period & Country

(Number of Companies)

Host Region	-1975	76-80	81-85	86-90	91-95	96-	Total
North America	6	2	6	12	13	5	44
EC Nations	2	2	4	6	11	5	30
Other W. Europe	0	0	2	5	5	3	15
East Europe	0	0	1	1	2	1	5
China	0	0	1	2	5	1	9
Republic of Korea	2	1	4	4	3	3	17
Taiwan	3	1	5	6	3	4	22
ASEAN Nations	3	2	1	7	6	4	23
Other	2	2	1	2	3	2	12
Total	18	10	25	45	51	28	177

(311 respondents; multiple answers permitted)
(Source: MITI questionnaire survey, March, 1989)

Table 2-6 Motives for Overseas Expansion

	(No of Companies)
Trade friction (including import, export restrictions)	13
Cheaper labor	12
More abundant labor force (ordinary laborers)	10
Facilitate acquisition of advanced technology	8
Another division of company already operating overseas	33
Yen getting stronger	13
Avoid export profit instability due to exchange rate fluctuation	7
Facilitate raw materials acquisition	2
Expand sales channels in host & neighboring countries	56
Local government policy makes local production advantageous	9
Other	5

(311 respondents; multiple answers permitted)
(Source: MITI questionnaire survey, March, 1989)

(7) Regional Expansion

In terms of its applications, fine ceramics is a brand new industry. In terms of its mode of production, however, fine ceramics is one field within the traditional ceramics industry. Indeed, almost all of the fine-ceramics producers currently generating large sales are either companies which were already engaged in so-called classic ceramics, making such products as conventional insulators, or companies founded by people with backgrounds in classic ceramics. As a consequence of this, these large companies do not have their main offices located in Tokyo. Fine ceramics is an industry which has a regional origin and which has expanded regionally. Hence it is unusual among the high-tech industries in that it has deep ties with local regions. According to the questionnaire survey which MITI conducted this past March, many factories and research facilities are located outside of the Kanto or Greater Tokyo area, with many such factories and research facilities which are involved in fine ceramics being located in the Chubu, Kansai, and Kyushu regions. (Cf Table 2-7)

Table 2-7 Location of Fine Ceramics Factories, Research Facilities

Prefecture	Number of Factories	No of Research Facil
Hokkaido	4	2
Aomori	0	0
Iwate	0	0
Miyagi	5	3
Akita	2	0
Yamagata	2	1
Fukushima	4	3
Ibaraki	6	8
Tochigi	3	3
Gunma	2	2
Saitama	7	10
Chiba	8	12
Tokyo	6	14
Kanagawa	22	30
Niigata	2	2
Fukuyama	8	4
Ishikawa	3	2
Fukui	2	1
Yamanashi	3	0
Nagano	7	4
Gifu	9	2
Shizuoka	4	3
Aichi	27	21
Mie	6	4
Shiga	5	2
Kyoto	1	3

Table 2-7 [continued]

Prefecture	Number of Factories	No of Research Facil
Osaka	16	21
Hyogo	13	10
Nara	0	1
Wakayama	0	0
Tottori	0	0
Shimane	2	1
Okayama	9	4
Hiroshima	0	0
Yamaguchi	8	6
Tokushima	2	1
Kagawa	2	0
Ehime	3	2
Kochi	0	0
Fukuoka	10	8
Saga	5	5
Nagano	1	1
Kumamoto	0	3
Oita	0	0
Miyazaki	4	1
Kagoshima	4	1
Okinawa	0	0
Total	227	205

(MITI survey, March, 1989)

Under the influence of structural changes in Japanese industry, regionally based companies--particularly the small and medium-sized companies--are being forced to move into and expand in new fields. Such traditional ceramic fields as fire brick and tile are no exceptions, and companies in these fields are obliged by dwindling demand and other factors to move into new fields. When faced with such a prospect, the first field which such companies are likely to consider is fine ceramics. Such companies will tend to look at the production mode involved--namely baking or firing--and reason that this is similar to the production mode they are now using, and hence a relatively easy one to implement. They will also tend to entertain high expectations concerning the demand growth and potential of fine ceramics products, these being oriented toward high-tech industrial users. According to a survey conducted last year by MITI, there are about 40 organizations in Japan which are engaged in exchanging information and doing survey research with the objective of moving into fine ceramics (cf Appendix 6). Most of these organizations have memberships of small and medium-sized companies, and are guided by national or public testing and research facilities in the

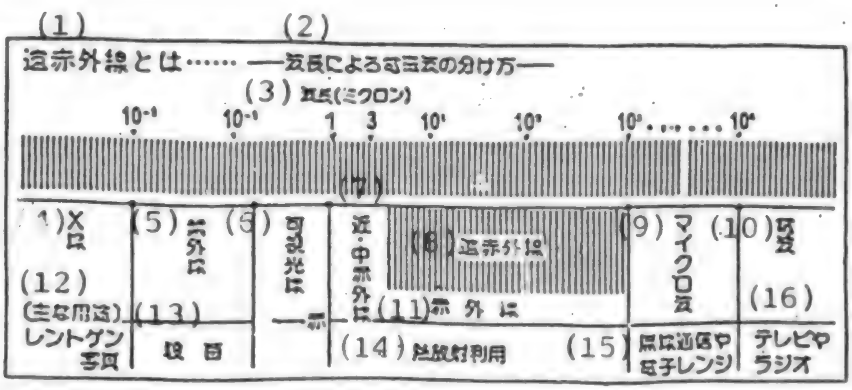
region. The members entertain views much like those noted above. The field of fine ceramics, however, while being part of the broader field of ceramics in general, is completely different in terms of the raw materials and manufacturing methods which must be used. The production of fine ceramics requires extremely rigorous quality control and exacting production control. Performance demands are severe, the speed of technological breakthroughs is fast, and the investments required in human and capital resources--both for R&D and for plant and equipment--are staggering. Fine ceramics is also a very diversified field, so, if a suitable product area can be found, this may indeed be a promising field for a small or medium company which has been engaged in the ceramics business. In terms of the technological and capital resources demanded, however, this may not necessarily be an easy field for a small or medium-sized company to get into.

For this reason, a number of things are critical in order for regional industries--particularly the small and medium-sized businesses--to move into the fine ceramics field. These things include ascertaining demands before they arise (particularly important for the small and medium companies), information exchanges with other industries, universities, and government agencies, and information exchanges through other organizations throughout Japan bent on the same purpose. It was with just such a perspective that the *Fain Seramikkusu Kanren Dantai Renraku Kyogikai* (Fine Ceramics Organization Liaison Conference) was formed in October of last year. This conference is made up of over 20 of the regional organizations described above. The aim of this conference is to mutually promote regional industry--and the fine ceramics industry in particular--by holding an annual national convention and sharing information among organizations on a day-to-day basis. Participating in the conference are the Japan Fine Ceramics Association and the Fine Ceramics Center, each of which is now supporting further regional expansion of the fine ceramics industry, in the context of its own organizational perspective.

(8) Far-Infrared Ceramic Products

Far-infrared radiation is electromagnetic waves having a wavelength of from 3μ to 1000μ or so (cf Figure 2-9). Absorption into water and organic substances is good, and this radiation has been used for a long time in drying and heating applications. Far-infrared radiation is emitted from other sources than fine ceramics, but in drying and heating applications it is necessary to heat the far-infrared radiating body, so fine ceramic products are usually used because they are heat-resistant and insulative. More recent applications in which the characteristics of far-infrared radiation are exploited include heat sources for food drying and low-temperature saunas. In food drying--such as coffee roasting and the baking of rice cakes--not only can the food be dried efficiently and at lower temperatures than with conventional drying, but it is reported that the finished food products do not lose their original fresh taste and aroma.

Figure 2-9   Far-Infrared Radiation



Key:

1. What far-infrared radiation is
2. --Classification of electromagnetic radiation according to wavelength
3. Wavelength (microns)
4. X-rays
5. Ultraviolet radiation
6. Visible light
7. Near-infrared radiation
8. Far-infrared radiation
9. Microwaves
10. Short waves
11. Infrared radiation
12. X-ray photographs
13. Sterilization
14. Heat radiation
15. Wireless communications and microwave ovens
16. Television and radio

In more recent years, particularly since 1985, ceramic products have appeared which make use of far-infrared radiation in completely different ways than conventionally. In the conventional way, the far-infrared radiating body was heated to a high temperature. In the new ways, the radiating body is not heated at all. Now, for example, we have apparel that is made using fibers into which far-infrared radiating bodies have been kneaded, as well as sheets and films of far-infrared radiating material which are used to preserve the freshness and enhance the flavor of foods. Many such products are now on the market. The far-infrared radiating materials used in these products are generally fine ceramics materials. This past February, MITI sent a questionnaire to some of the companies manufacturing far-infrared products. In Table 2-8 are listed the manufacturing and sales points for each category of such products. This table is also indicative of recent trends. Of particular note among the results of this survey is the great number of apparel products which now use ceramic materials at room temperature.

Table 2-8 Manufacturing Trends in Far-Infrared Products, by Category
(Numerical values are numbers of cases)

表2－8 遠赤外線製品分野別の製品企業化動向（件数）

	(1) 参入時期（昭和）	(2) 製品件数合計	1956 to 1965	1966 to 1975	1976 to 1985	1986, 1987	1988	(3) 不明
(4)	加熱，乾燥，暖房等	80	5	5	22	19	22	7
(5)	食品加熱	44	0	1	4	17	21	1
(6)	サウナ	14	0	0	11	1	2	0
(7)	医療機器等	6	0	0	1	2	3	0
(8)	加熱分野合計	144	5	6	38	39	48	8
(9)	衣料品等	63	0	0	2	10	39	12
(10)	活水器，マドラー等	20	0	0	0	8	9	3
(11)	鮮度保持	8	0	0	0	0	4	4
(12)	非加熱分野合計	91	0	0	2	18	52	19
(13)	粉体等の素材	17	1	1	3	5	4	3
(14)	合　　計	252	6	7	43	62	104	30

(15)（通商産業省平成元年1月調査）

Key:

1. Period of participation
2. Total number of products
3. Unknown
4. Heating, drying, indoor heating
5. Food heating
6. Sauna
7. Medical equipment
8. Total for heating applications
9. Apparel
10. Activated water devices, etc
11. Freshness preservation
12. Total for non-heating applications
13. Powders, other materials
14. Total
15. MITI survey, January, 1989

Despite the fact, however, that many products are being manufactured and sold which use far-infrared radiation in non-heating applications, the

scientific basis for the effectiveness of these materials is not well understood, as is pointed out in many quarters. It was for this reason that the Far-Infrared Ceramics Technology Study Committee was formed last year within the Japan Fine Ceramics Association, under the direction of MITI. This committee--made up of specialists in the field--has been evaluating the current situation and studying various technological problems involving far-infrared radiation. An interim report was issued this past April. This report contains the following summary.

> And finally, in this report, we have considered various problems involving far-infrared ceramics. Due to the wide range of fields in which this technology is used, however, and the limited timeframe for our studies, we have reached no final conclusions. In particular, while product development has been underway in the non-heating field for some years now, this field has yet to be subjected to adequate scientific investigation. Based on what we have learned to date, it would be unwise to jump to the conclusion that this [use of far-infrared radiation] is effective. Nevertheless, while much is still unknown about the effects of far-infrared radiation, it is reported that some kind of organic or biological change occurs when these ceramics are used, and we need to conduct studies in a wide range of areas before making final evaluations.

With this report in hand, MITI this year commissioned the Japan Fine Ceramics Association to form a committee made up of specialists from industry, academia, and government, conduct in-depth studies of various technological problems, and propose policies and measures to implement in dealing with these problems.

2-2 Fine Ceramics Utilization Today

(1) Fine Ceramics Utilization According to Properties

Products in which fine ceramics are used are listed in Table 2-9, according to the property utilized.

<1> Electromagnetic Properties

Electromagnetic properties include insulative properties, dielectric properties, piezoelectric properties, pyroelectric properties, semiconductor properties, superconductor properties, and ion-conduction properties, etc. Insulative properties are used in IC packages, IC boards, heat-radiating insulative boards, and electron tubes, etc. The materials used in these applications include aluminum oxide, silicon carbide, beryllium oxide, and

Table 2-9 Fine Ceramics Applications (Products)

Property Exploited	Application (Product)
«««Electromagnetic Properties»»»	
Insulative	IC packages, IC boards, heat-radiating insulative boards, electron tubes
Dielectric	Capacitors, dielectric resonators for microwave applications
Piezoelectric	Ignition elements, electric wave filters, piezoelectric buzzers, ultrasonic elements, elastic-surface-wave elements
Pyroelectric	Infrared sensors
Semiconductor (thermistors, varistors, etc)	Low-resistance heater elements (high-temperature electric furnaces), humidity sensors (microwave ovens), temperature sensors (temperature controls, electronic thermometers), varistors (voltage stabilizer elements, lightening arresters), self-controlled low-resistance heating elements (electronic jars, blanket driers, hair driers), gas sensors (gas-leak alarms)
Ionic conductance	Oxygen gas sensors (for automobiles, steelmaking), battery electrolyte
Magnetism	Memory elements, transformer cores, magnetic heads, magnetic disks, magnetic tape, permanent magnets, rubber magnets
«««Mechanical Properties»»»	
Hardness, wear-resistance	Cutting tools, grinding & polishing materials, excavating bits, mechanical seals, bearings, rollers, knives and blades
High strength	Engine parts, gas turbine parts, combustion nozzles
High elasticity	Golf club shafts, fishing rods
Lubrication	Solid lubricants, mold release agents
«««Biological & Chemical Properties»»»	
Biological affinity	Artificial bone, artificial dental roots, artificial joints
Carrier properties	Fixed enzyme carriers, catalytic carriers
Anti-corrosiveness	Chemical industry equipment parts, heat exchangers, scientific equipment, materials used in nuclear energy
Catalytic properties	Environment-protection catalysts, catalysts used in chemical industry
Absorbance	Adsorbents

Table 2-9 [continued]

Property Exploited	Application (Product)
«««Thermal Properties»»»	
Heat resistance	Engine parts, heat-resistant structural materials, materials used in nuclear fusion reactors
Thermal insulation	High-temperature thermal insulation, tiles for space reentry vehicles
Thermal conductivity	Heat-radiating insulator boards
Heat-resistive impact	Honeycombs for catalytic carriers
«««Optical Properties»»»	
Fluorescence	Fluorescent bodies, materials used in color TV tubes, laser materials
Translucence	High-pressure sodium lamp light emitter tubes
Translucent polarization	Optical memories, optical shutters, displays
Light-transmissive	Fiber optics

aluminum nitride. Dielectric properties are used in making capacitors smaller and more highly reliable, and also in making inductive materials for microwave applications. The materials used include barium titanate, strontium titanate, and lead perovskite. Piezoelectric properties are used in piezoelectric ignition elements, vibrators, piezoelectric buzzers, piezoelectric filters, and elastic-surface-wave elements. The materials employed include [polycrystalline] lead zirconate titanate (PZT), PLZT [Pb-based lanthanum-doped zirconate titanates], zinc oxide, mercury, lithium niobate, and lithium tantalate. Pyroelectric properties are utilized in infrared sensors. Applications of semiconductor properties include low-resistance heater elements, constant-temperature heating elements using PTC characteristics, temperature sensors using NTC characteristics, and in other elements in varistors and gas sensors, etc. The materials used include barium titanate, strontium titanate, zinc oxide, titanium oxide, tin oxide, and silicon carbide, depending on the application. As to superconductor properties, oxide-based superconductors have been developed in recent years which have a Tc above that of the temperature of liquid nitrogen, and practical applications are hoped for. In the area of ionic conductivity, ß-aluminum oxide is used in solid electrolytic cells and stabilized zirconium oxide is used in oxygen sensors. In the area of magnetism, ferrite is the typical substance used, the magnetic properties of which are used in transformers, magnetic heads, and electric wave absorbers. The materials used include manganese-zinc ferrite and nickel-zinc ferrite. In the area of hard magnetic materials, barium ferrite is used in permanent magnets and rubber magnets. In the field of magnetic recording materials, gamma iron oxide is used in magnetic tape and magnetic disks.

<2> Mechanical Properties

Mechanical properties include high hardness, high strength, wear resistance, and high elasticity. High hardness and wear resistance are used in improving longevity and precision in mechanical structural materials, as well as in cutting, grinding, and polishing materials, mechanical seals, bearings, and rollers. The materials used include aluminum oxide, boron carbide, diamonds, cubic boron nitride (c-BN), silicon nitride, and silicon carbide. High strength is used to improve heat efficiency in high-temperature thermal engines, and in increasing the useful life of mechanical structural components, as well as in engine and turbine components. The materials used include silicon nitride, silicon carbide, sialon, and partially stabilized zirconium. High elasticity is employed in sporting and leisure equipment with the use of fine ceramics fibers. Lubricating properties are exploited in solid lubricants and mold release agents with the use of hexagonal silicon nitride (h-BN) [sic] and molybdenum disulfide.

<3> Biological, Chemical Properties

Biological properties include biological affinity and carrier properties. Biological affinity is used in artificial dental roots, artificial bones, and artificial joints. The materials used include aluminum oxide and apatite hydroxide. Using the carrier properties, silica and alumina are used as carriers for fixed enzymes. Chemical properties include anti-corrosiveness, catalysis, and absorbance. Anti-corrosive properties such as acid resistance, alkali resistance, and melt-resistant metallic properties are exploited to enhance the useful life of various components. These [components] are used in chemical equipment and heat exchangers. The materials used include aluminum oxide, silicon nitride, and silicon carbide. As catalysts, aluminum oxide and titanium oxide are used in environmental protection and chemical industry applications. For its adsorbent properties, porous aluminum oxide is used as an absorbent.

<4> Thermal Properties

Thermal properties include heat resistance, thermal insulative properties, and thermal conductive properties. Heat resistance is used in enhancing the longevity and efficiency of components, particularly in engine components and heat-resistant structural materials. The materials used include aluminum oxide, silicon carbide, and silicon nitride. Thermal insulative properties are used generally to enhance thermal efficiency, one application being the insulative tiles used in space reentry vehicles. The materials used include fibers with an alumina-silica or potassium titanate base. Thermal conductive properties, such as heat-radiating properties, are used in heat-dissipating boards for electronic and electrical components. The materials used include beryllium oxide, aluminum nitride, silicon carbide, and diamonds. Heat-resistive impact properties are used in catalytic carriers, implemented with cordierite.

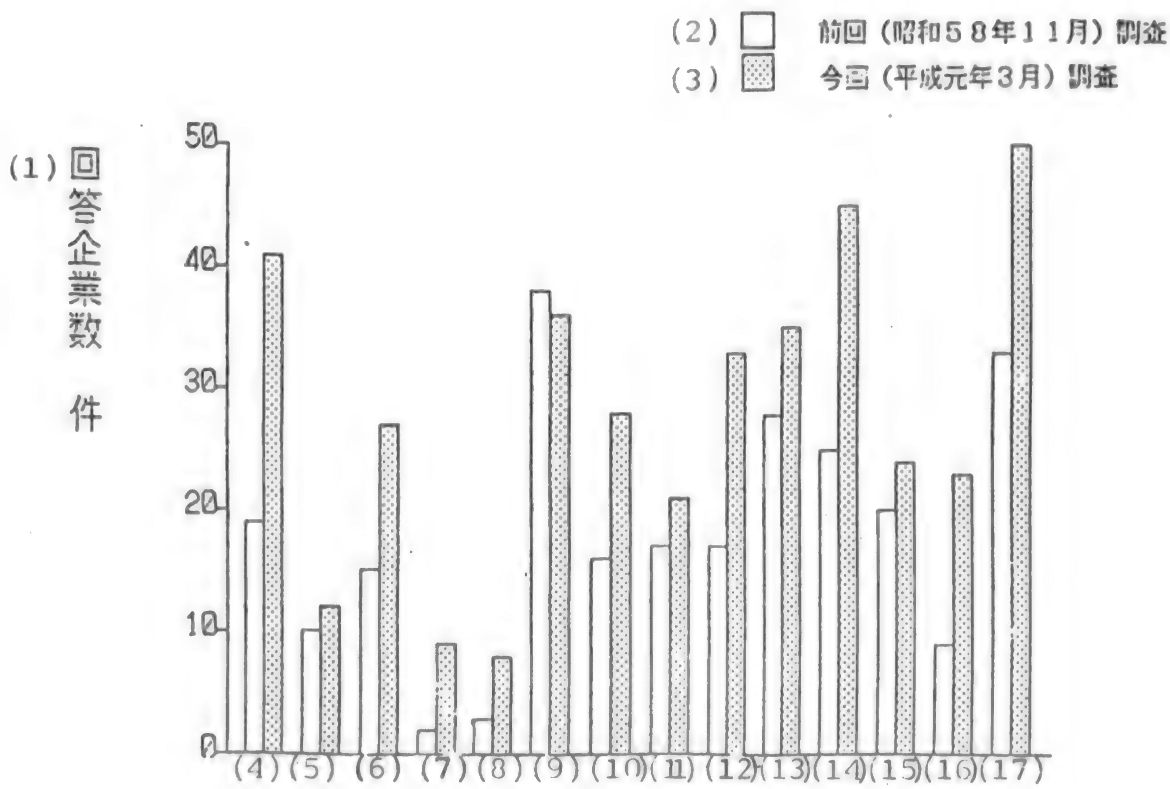
<5> Optical Properties

Optical properties include fluorescence, translucence, translucent polarizing, and light-transmissive properties. Fluorescence is used in color television tubes and display elements (zinc sulfide and yttrium sulfate) and solid lasers (ruby, YAG). For its translucence, aluminum oxide is used in light-emitting tubes in sodium lamps. Translucent polarizing properties are used in optical memories, optical shutters, and displays where, in addition to achieving high translucence, the optical properties are altered in magnetic fields. Light-transmissive properties are used in the field of fiber optics.

(2) Fine Ceramics Utilization According to Application

When we look at utilization trends by field of application as indicated by the results of a MITI survey (giving total numbers of companies involved in planning, R&D, and testing, at each level of utilization), we see that the

Figure 2-10 Utilization Trends by Application Field
(311 respondents) (MITI survey, March, 1989)



Key to Figure 2-10:

1. Number of companies so answering
2. Previous survey (Nov 83)   3. This survey (Mar 89)
4. Motors for industry and power generation
5. Nuclear power equipment
6. Equipment related to energy development
7. Equipment related to space development
8. Equipment related to ocean development
9. Transportation equipment   10. Metal processing equipment
11. Chemical equipment   12. Precision equipment
13. Fluid machines   14. General industrial machinery
15. Information, communications-related equipment
16. Medical equipment   17. Other

number of user companies is growing in all fields except transportation equipment. This growth is particularly notable in industrial and power-generation motors, energy-related equipment, metal processing equipment, precision equipment, general industrial equipment, and medical equipment (cf Figure 2-10).

We next present examples of utilization, by application field and stage, i.e. planning survey stage, R&D stage, testing stage, and utilization stage.

Table 2-10 Examples of Utilization by Application Field, Stage (P&S = planning & survey stage, R&D = research & development stage, TS = trial use stage, US = utilization stage)

Industrial, Power-Generation Motors

P&S Gas turbine parts (blades, rotors, scrolls, nozzles, combustion chambers)

R&D Gas turbine parts (blades, rotors, scrolls, combustion chambers)
Diesel engine parts

TS Valves, pipe systems, combustion chamber parts, insulative materials for electric power transmission

US Valves, glow plugs, slurry transport equipment, ceramic lining, filters, burners

Nuclear Power Equipment

P&S Materials used in nuclear fusion reactors

R&D Materials used to fix waste products in glass, materials for next-generation light-water reactors, catalytic carriers for exhaust gas recrystallizers

US Mechanical seals, materials used in melting furnaces to process radioactive wastes

Table 2-10 [continued]

Energy-Development Equipment	
P&S	Fuel cells, thermal insulation, electrode materials, far-infrared heaters
R&D	Fuel cells, solar cells, burner materials
TS	Heat exchangers, boiler materials, valve seats, insulative materials for electric power transmission
US	Heater materials, burner materials, inner walls in industrial furnaces
Space-Development Equipment	
P&S	Thermal insulation, bearings, space-experiment equipment
TS	Materials used in plasma screws
Ocean-Development Equipment	
R&D	Materials used in liquid-pressure actuators
Transport Equipment (Automobiles, Ships, Aircraft)	
P&S	Gas turbines, large jet engine parts
R&D	Gas turbines, aircraft cabin materials
TS	Valve system parts, bearings, thermal insulation coatings for jet engines
US	Mechanical valves, glow plugs, sensors, catalytic carriers, turbine blades, turbocharger rotors
Metal Processing Equipment	
P&S	Bearings, coils for induction ovens/furnaces
R&D	Die-cast mold materials, plating rollers
TS	Bearings, grindstones, polishing stones
US	Cutting tools, superhard tools, b'ts, guide rollers, main shafts
Chemical Equipment	
P&S	Anti-corrosive seals, valves, heat exchangers
R&D	Valves, gas separation films
TS	Heat exchangers, incinerator materials
US	Mechanical seals, sensors (gas, oxygen), nozzles, valves, filters
Precision Equipment	
P&S	Machine tool parts
R&D	Sensors (temperature, gas), gas bearings
TS	Bearings
US	Bearings, gas sensors, actuators
Fluid Machines (Pumps, Hydraulic Equipment)	
P&S	Chemical pump components
R&D	Bearings for high-pressure water pumps, high-volume slurry pumps
TS	Mechanical seals, valves, shafts, bearings
US	Mechanical seals, bearings, valves, filters, pump components

Table 2-10 [continued]

<u>General Industrial Equipment</u>
R&D Seal materials, actuators, bearings
TS Grinding bits, screws, rollers, ceramic carbon
US Mechanical seals, yarn guides, bearings, grindstones, cutters

<u>Information, Communications Equipment</u>
P&S Electronic devices
R&D Electronic devices, EL display elements, garnet thin films
US IC packages, IC boards, capacitors, optical fiber, varistors, magnetic heads

<u>Medical Equipment</u>
P&S Artificial bones
R&D Artificial bones, ultrasound diagnostic equipment
TS Artificial bones
US Ultrasound diagnostic equipment, oxygen sensors, optical fiber

<u>Homebuilding Equipment</u>
R&D Heat-emitting bodies
US PTC heaters, gas water heaters

<u>Distribution, Service-Related Equipment</u>

<u>Office Equipment</u>
US Boards for thermal heads

<u>Sports, Leisure Equipment</u>
US Golf club shafts, spikes, fishing equipment

<u>Household Equipment</u>
TS Knives
US Burners for cooking stoves, plates for fried food

<u>Luxury Items</u>
US Decorative items

<u>Other</u>
R&D Catalytic carriers
TS Musical instruments
US Crucibles, heat-emitting bodies, catalytic carriers

(Source: MITI questionnaire survey, March, 1989)

<1> Industrial, Power-Generation Motors; Energy, Nuclear Power Equipment

Now in use in the fields of motors for industry and power generation, and energy- and nuclear-power-related equipment, are such small components as valves, ceramic linings, burners, and mechanical seals, as well as coatings. Under research and development, meanwhile, are materials for gas turbines and fuel cells. In the fields of equipment for space and ocean development, experimental use is being made of fine ceramics materials in plasma propulsion units for satellite vehicles, while research is being done on heat-shield tiles, ceramic composite materials, bearings, and hydraulic actuator components.

<2> Transportation Equipment

The field of transportation equipment is dominated by the automotive sector, in which the fine ceramics products now in use include various sensors, functional materials such as catalytic carriers, small components such as mechanical seals and glow plugs, and turbocharger rotors. Power valve parts and bearings are also being used experimentally. Under research and development are ceramic gas turbines for automotive use, a product which is positioned as the strongest candidate for the next generation of engines.

<3> Industrial Machines

In the field of industrial machines, fine ceramics are used in relatively large quantities in cutting tools. Other applications include mechanical seals, bearings, sensors, nozzle valves, valve materials, and bearings [sic]. R&D work is also moving ahead on heat exchangers and pump components.

<4> Information, Communications Equipment

Fine ceramics applications in the area of information and communications equipment include IC packages, IC boards, and capacitors, as well as piezoelectric applications such as filters, vibrators, and elastic-surface-wave filters, magnetic applications such as various magnetic cores, magnetic heads, magnetic recording elements, and permanent magnets, semiconductor applications such as thermistors and varistors, and light-transmissivity applications in fiber optics. The amount of this utilization is large. Meanwhile, R&D work is continuing on various new devices.

<5> Medical Equipment

Practical applications in the field of medical equipment include ultrasound diagnostic equipment (in which ultrasonic vibrators are used), sensors, and fiberscopes. Fine ceramics are also used as biological materials in artificial dental roots, while artificial bones and artificial joints are under research and development.

<6> Sports, Leisure Equipment; Household Items

In the areas of sports and leisure equipment and everyday household items, composites containing fine ceramics fibers are used in golf club shafts, tennis rackets, skis, and fishing equipment. Ceramic coatings are also used on golf club faces and fishing-pole guide rings. Fine ceramics are also used in such household items as cutlery, stove burners, and plates for fried foods. Fine ceramics pharmaceuticals are being produced experimentally.

(3) Promising Fields

According to the results of the MITI questionnaire survey, there are many promising fields for fine ceramics applications. These include the fields of energy, space, transportation equipment (particularly the automotive sector), precision machinery, information and communications, and medical equipment.

Promising materials are listed specifically, by field, in Table 2-11. The greatest expectations are being focused on various structural materials in fields which include industrial and power-generation motors, energy-related equipment, and turbine and engine components for transport equipment. Expectations are likewise high for various electronic device materials for use mainly in the field of information and communications equipment, and for bioceramics materials in the medical equipment field. And while R&D has yet to get underway, it is hoped that fine ceramics materials will be used in oxide-based superconductor power equipment and transport equipment, as well as in superconductor electronic devices for use in information and communications equipment.

Table 2-11 Promising Fields for Fine Ceramics Materials

Field	No of Companies	Specific Examples
Industrial, power-generation motors	135	Gas turbine materials (blades, rotors, combustion chambers), engine parts, superconductors, heaters, fuel cells, coal gasification reactor linings, high-temperature blowers, pump components
Nuclear power equip	64	Nuclear reactor materials, nuclear power pump components, uranium melting crucibles, coating materials, control rods, moderator materials
Energy-development equipment	95	Gas turbine materials (blades, rotors, combustion chambers), solar cells, fuel cells, heat exchangers, superconductor materials, high-temperature catalysts for exhaust-gas purification

Table 2-11 [continued]

Field	No of Companies	Specific Examples
Space-development equipment	76	Light-weight structural materials, space reentry vehicle materials, thermal insulation, electromagnetic wave absorbing materials
Ocean-development equipment	40	Pipes, pumps, seawater purification systems, anti-corrosive structural materials
Transport equipment (automobiles)	184	Diesel engine parts, gas turbine parts, sensors, catalysts, catalytic carriers, bearings, engine peripherals
Transport equipment (ships)	153	Engine parts, gas turbine parts, superconductor materials, superconductor ships
Transport equipment (aircraft)	72	Engine parts, internal wing components, structural materials
Metal processing equip	119	Tools, bearings, rollers
Chemical equipment	108	Catalysts, catalytic carriers, pumps, heat exchangers, mechanical seals
Precision equipment	118	Bearings, sensors, surface plates, tools, piezoelectric actuators
Fluid machines (pumps, hydraulic equipment)	114	Mechanical seals, bearings, pumps, nozzles, pipe system materials
General indus equip	98	Bearings, heat-emitting bodies, piezoelectric elements, far-infrared heaters
Info & comm equipment	150	Optical fiber, sensors, IC packages, electromagnetic wave absorbers, capacitors, actuators, optical disc memories, display elements
Medical equipment	129	Artificial bones, artificial joints, artificial dental roots and crowns, sensors
Homebuilder materials	69	Thermal insulation, sensors
Distribution, service equipment	10	Magnetic cards, sensors
Office equipment	35	Ballpoint pens, scissors, knives
Sports, leisure equip	53	Golf clubs, spikes, fishing equipment
Household items	68	Scissors, carving knives, paring knives, tableware, tennis rackets [sic]
Luxury items	26	Artificial jewels, speakers
Other	8	

(311 companies responding) (MITI questionnaire survey, March, 1989)

2-3 Problems in Fine Ceramics Industry

(1) Development in Conjunction With Other Industries, Fields

In the basic materials industry, in general, it is difficult to independently develop a finished product from scratch. It is usually necessary to work closely with users and other related industries in carrying on R&D, developing applications, and seeking to generate wider demand. New materials are somewhat glamorous, since they perform in ways which conventional materials do not, but there is no backlog of experience in using new materials. The user, therefore, is often unable to adequately verify how reliably a new material will perform, while the producer finds it difficult to properly identify the user's needs. Hence, at every stage of R&D and application development, the manufacturer must work very closely with the users and other related industries.

In the broader field of new materials, fine ceramics are characterized by high strength and heat resistance, but users also find them hard to use due to their "brittleness," or poor "toughness." Other factors which discourage users from employing fine ceramics are the paucity of data on these materials, as compared to the data on metals, and the inadequacy of design technology for fully exploiting fine ceramics materials. Fine ceramics applications are extremely diversified, moreover, and fine ceramics materials cannot be used in the same way that other materials can. In other words, they cannot be delivered in the form of ingots or plates or bars which are then processed or machined by the user. The producer either makes the finished product or fabricates the component. Typically, the manufacturer must fully understand the final application and the performance demanded before developing a fine ceramics product. For the fine ceramics manufacturer to conduct R&D on every conceivable application, however, is very onerous in terms of both capital and personnel. Accordingly, in order to develop fine ceramics technology and promote demand growth, the manufacturer must work very closely with the automobile, electronics, or electrical industry, or other user, as well as with other related industries, in exchanging information and conducting joint research. This is more critical for fine ceramics than for other new materials.

The Japan Fine Ceramics Association, incorporated in 1986, started in 1982 as the Fine Ceramics Association. This body is made up of manufacturers and users. The exchange of information between these member organizations is an essential factor in expanding demand in the future, and the activities of the association need to be intensified. The Japan Ceramics Association has for some time published monographs and a scientific journal covering the entire field of traditional ceramics [*yogyo*]. This organization must now diversify its activities to keep abreast of the rapid advances now being made in new materials research in such ceramic fields as new glass, new diamonds, and new carbon. In other words, the applications for inorganic new materials involve products outside of the range of such conventional

ceramics products as electronics, machine, and automotive components. The technological progress being made in some of these fields is truly amazing. In doing materials research in these fields, exchanges between researchers in other scientific fields such as electronic and mechanical engineering is indispensable. By holding symposiums in which this association participates with other scientific societies, and promoting membership by researchers in other fields, interdisciplinary and inter-field scientific exchange must be fostered. The Fine Ceramics Center is pushing the development of testing and evaluation methods in the interest of facilitating evaluations among fine ceramics users and producers and promoting wider use. The Center was incorporated in 1985 for the purpose of achieving these objectives. Good facilities have been established, but the organization still does not have a solid technological base to work from. Hence it is necessary for the Center to upgrade its organizational structure and technical competence by drawing broadly from the resources of private industries, universities, and governmental organizations. (Cf Appendix 7)

(2) Problems in Promoting Demand Growth--Cost, Reliability Factors

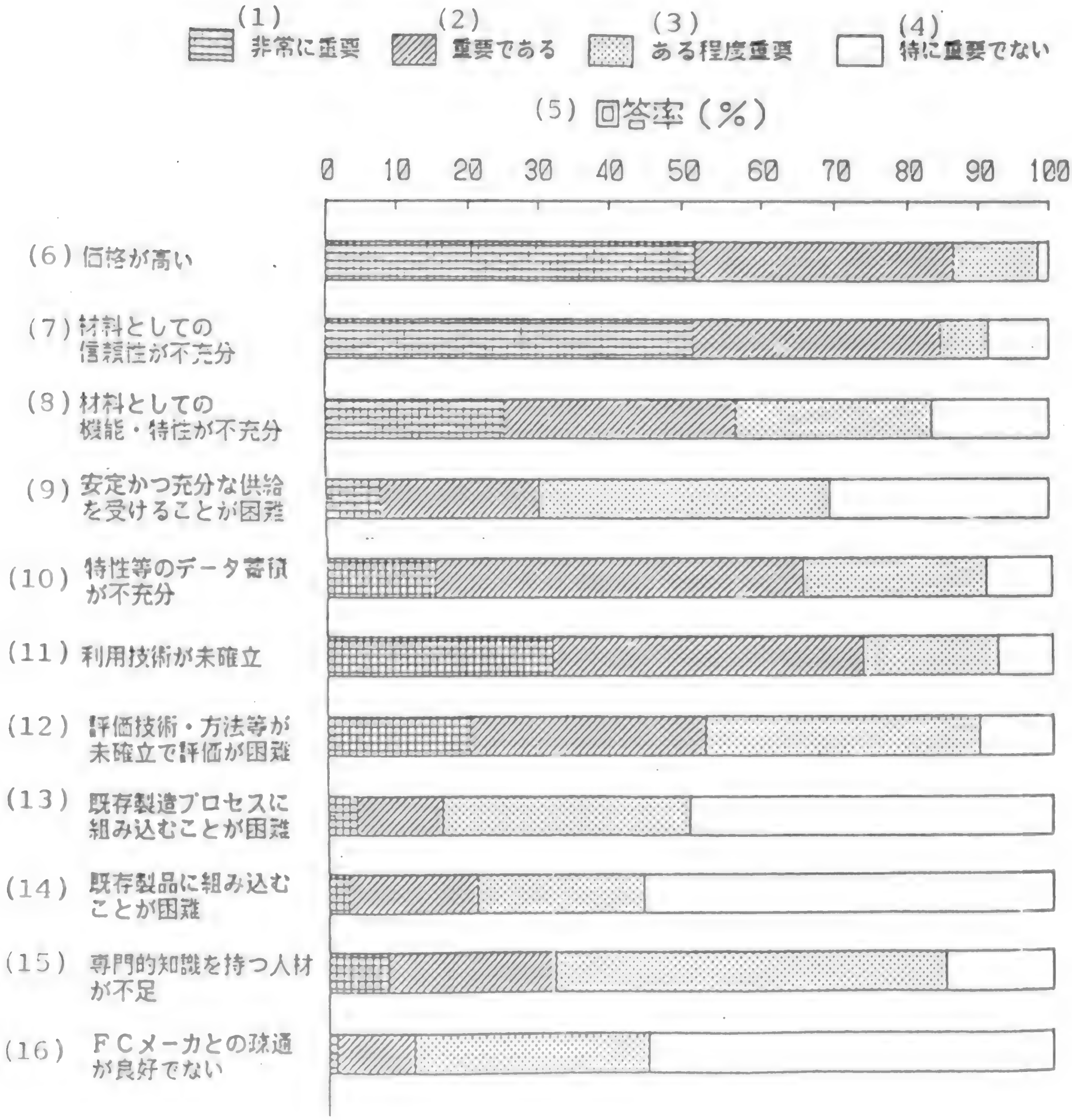
Two reasons frequently cited for the lack of demand growth in fine ceramics--particularly in the field of structural materials--are cost and reliability. When these reasons are alluded to, it is assumed that we are talking about materials to replace metals (i.e. the materials currently used). It is, however, difficult to obtain good performance from conventional metallic materials in fields where high-temperature, high-strength materials have to be used at temperatures in excess of 120°C. When comparing costs in these fields, therefore, one cannot simply compare the cost of the materials, but must also consider the effectiveness [of fine ceramics] in reducing the overall cost of the system by enhancing the thermal efficiency through high-temperature implementation. This goes without saying. When we examine the demand for fine ceramics, however, we find that not all of these applications fields are such as those described above in which only fine ceramics can be used. For the present, such fields in which conventional materials cannot be used are still in the R&D stage. In order to generate demand growth, therefore, the properties of fine ceramics must be fully exploited. Not only so, but costs must be reduced and reliability guaranteed in fields where it is possible to replace such competing materials as metals with fine ceramics.

The questionnaire survey conducted this past March by MITI addresses a number of the problems which users face in employing fine ceramics materials and components. Many user companies indicated that the biggest problems were high prices and inadequate material reliability (cf Figure 2-11).

Looking first at the high-price issue, we see that a number of causes are possible. To begin with, production volumes are small, so that manufacturers cannot realize any economy of scale with larger production facilities. This alleged cause of high prices, however, applies equally well to

other materials, and is hardly a problem peculiar to fine ceramics. And if the production of raw materials and component materials expands in the future, this problem should be resolved.

Figure 2-11 Problems in Using Fine Ceramics Materials, Components



Key to Figure 2-11:

1.	Very important	2.	Important
3.	Somewhat important	4.	Not particularly important
5.	Percent of respondents (%)	6.	Price is high

7. Inadequate reliability of material
8. Inadequate functionality, properties in material
9. Difficulty in obtaining stable, adequate supplies
10. Inadequacy of available data on properties, etc
11. Application technology not fully developed
12. Evaluation techniques, methods not established; hard to evaluate
13. Difficult of incorporating into current manufacturing processes
14. Difficulty of incorporating into existing products
15. Shortage of personnel with specialized knowledge in field
16. Poor liaison with FC manufacturers

The next things that are conceivable as a causes of high costs which are peculiar to fine ceramics are problems in manufacturing processes and the fact that testing and evaluation techniques have not yet been perfected. The production costs, by process, for various fine ceramics materials and components, based on a MITI survey, are listed in Table 2-12. The values in the table represent, of course, the averages of the companies [responding], and naturally differ greatly depending on the raw materials used, the manufacturing process, and the material or component in view. At any rate, the complexity and length of fine ceramics manufacturing processes in general are factors which push up the price. The molding and machining/processing of complex shapes, in particular, is a cause of higher prices. The more fundamental reasons behind these factors involve problems that are peculiar to fine ceramics, such as the difficulty of molding them because the initial raw material is a powder, or the fact that the process of baking inevitably results in some shrinkage, making a final processing step indispensable, or again the extreme hardness of the material which, while being an asset in the finished product, nevertheless complicates processing in the manufacturing stage.

Table 2-12 Relative Cost of Fine Ceramics Processes [cf Note]

Cost Component	IC Packages	Wear Resistant Items*	Turbocharger Rotors
Cost of raw materials	30	10	20
Powder preparation	5	5	5
Molding	10	10 - 20	10 - 20
Baking, firing	10	10 - 20	20
Machining, processing	20 - 40	40	15 - 20
Testing, evaluating	10	10	15 - 30

Note to Table 2-12: The figures represent numerical averages of multiple company responses; the percentages vary greatly according to the raw material used and the product in view.

The variation in performance in fine ceramics materials and components is slightly larger than in other materials, and non-destructive inspection techniques and life-span measuring procedures have not yet been perfected. For these reasons, excessively exacting specifications are demanded in machine components, for example, and the entire lot is subjected to testing--something which is not necessary with other (metallic) materials. This results in higher testing and evaluation costs. This cost is particularly high in something like a turbocharger (cf Table 2-12) which involves complex shapes and requires very high reliability.

In order to resolve these problems, R&D efforts must be made to improve the reliability of fine ceramics materials, and manufacturing methods--such as the so-called "near-net-shape" method (molding method in which product dimensions after baking are within allowable dimensional tolerances) which requires almost no machining or processing--must be developed. Brand new processes must also be developed in which powdered raw material is not used, i.e. in which products are manufactured from a gas or liquid phase. These efforts should produce lower costs. Research work is already being done on non-destructive testing methods for fine ceramics, and the testing and evaluation technology under development is urgently needed in order to improve reliability and reduce costs. But what is most important in the interest of expanded utilization is closer cooperation between manufacturers and users. Fine ceramics materials are new. Hence the design technology and system technology available to fine ceramics users are extremely inadequate. Metal design technology is currently being used for fine ceramics, but this will not do. Metals are basically ductile materials, while fine ceramics are basically brittle materials. Hence the application technology should be fundamentally different. It is of course to be hoped that R&D efforts to make fine ceramics materials tougher will result in materials which are highly reliable and easy to use. Nevertheless, the perfection of utilization technology designed specifically for fine ceramics and the unique properties thereof is urgently needed. To realize this goal, manufacturers and users should cooperate closely in sharing information and discovering new applications.

(3) Improving Industrial Infrastructure

Critical to the future development of the fine ceramics industry is the establishment of an improved industrial base (infrastructure). This will involve the development and standardization of material testing and evaluation procedures, the creation of databases, the compilation of statistics, and the acquisition and training of qualified personnel. Such an infrastructure will be the common property of companies in the industry, univer-

sities, research institutions, and government interests. This point was strongly emphasized in the Fine Ceramics Basic Issues Forum (chaired by Seiichi Ishizaka; a personal advisory board to the chief of the Consumer Goods Industries Bureau under MITI) held in August, 1984. Subsequently, in 1985, the Fine Ceramics Center was established, followed in 1986 by the foundation of the Japan Fine Ceramics Association (through the incorporation of the former Fine Ceramics Association) for the purpose of developing and standardizing testing and evaluation techniques. In 1986, MITI began publishing *Fine Ceramics Statistics*. With these activities the industrial infrastructure is gradually taking shape.

An industrial infrastructure, however, is the result of many years of development and data accumulation, and is not something that can be created in a short period of time. In addition, the high levels to which Japanese technology has now attained make it very difficult to adopt the conventional approach to creating an industrial base or infrastructure in Japan whereby technology and other needed resources are imported from abroad. Establishing an adequate industrial base is expected to be very costly, in terms of capital, for the fine ceramics industry due to the fact that it is still in the development stage. Accordingly, the establishment of a solid industrial base is an urgent necessity if the fine ceramics industry is to expand. This demands the collective efforts of industry, academia, and government.

<1> Development & Standardization of Testing & Evaluation Techniques, Database Creation

At the present time, the task of developing and standardizing testing and evaluating procedures in the fine ceramics industry (including users and producers) is still behind schedule. Hence it is difficult to make proper evaluations, which is a great hindrance to practical implementation. The standardization of fine ceramics [sic] will facilitate the comparison and exchange of data between users and makers, between different users, and between different makers. That will contribute greatly in promoting practical applications. In the context of research and development, moreover, it is imperative that data comparisons and evaluations be accurate, which presupposes standard terminology and standard testing and evaluation procedures. In other words, the standardization of terminology and of testing and evaluating techniques will promote more efficient research and development.

The Special Committee on New Materials Standardization (chaired by Seiichi Sanami, vice chairman of Keidanren; established under the Japan Industrial Standards Commission, Agency of Industrial Science and Technology, MITI), in a proposal (July of last year), set forth 219 categories in which standardization is necessary now. This was done in response to industrial demand, and based on a study made on the technological possibilities. Of the 219 categories, 124 are items in which the demand for standardization is particularly high. Roughly a third (69) of the 219 categories can be standardized

within a short period of time (within 2 to 3 years), while the remaining two thirds will require from 5 to 10 years. This task needs to be undertaken right away.

Turning to the subject of databases, the creation and maintenance of indigenous databases in Japan lags behind, and databases in the materials fields are all foreign-based. In the fine ceramics field, moreover, development overseas lags behind, and there is not a single database in the world for fine ceramics per se (cf Tables 2-13, 2-14). Currently, at the Fine Ceramics Center, work has gotten underway on the development of a database which contains primarily catalog information, but nothing at all has been done to develop a literature database or fact database such as is needed by users. If the work being done on standardization moves ahead, however, it will become possible to accumulate data based on uniform testing and evaluation procedures, which should in turn lead to the creation of a reliable fact database in the future.

Table 2-13 Materials-Field Databases Usable in Japan

	Number of Databases (%)		
	Foreign Made	Japanese Made	Total
All Fields	1270 (76.3%)	425 (23.7%)	1795
Materials Fields	20	0	20

(MITI "Database Register")

Table 2-14 Breakdown of 20 Databases in Materials Field (with overlapping)

Country		Material		Data Type	
United States	12	All materials	7	Literature	18
United Kingdom	8	Metals	12		
West Germany	1	Polymers	2	Facts	2
Japan	0	Fine Ceramics	0		

(MITI "Database Register")

<2> Personnel Training, Development

We begin our study of the availability of human resources in the field of inorganic materials (which includes fine ceramics) by looking at the numbers

of students in various fields of study at university, where human resource development takes place. We find that those students in [inorganic] materials-related fields are very few compared to the numbers in metal- and polymer-related fields. Metallurgy has a very long history of development, and the sudden rise of petrochemistry and polymer chemistry resulted in expanding university departments in these fields from the mid-1950's to the mid-1960's. Inorganic materials, on the other hand, while having an extremely long historical tradition, seemed to be slightly out of step with the advanced industries, as typified by the conventional ceramics [*yogyo*] field. Technology and science in this field, therefore, made little progress from what it had been from of old, and expansion in related departments--in terms of facilities or personnel--was very rare. There are presently only about one seventh as many students studying in the inorganic materials field at university as are in the field of polymer materials, and this ratio drops to roughly one tenth when we compare the number to those in metals-related fields. The situation is problematic in the extreme (cf Table 2-15). However, fine ceramics are being taken up as a new area of research in mechanical engineering departments and other departments, due in part to stimulation by the eye-opening R&D advances being made in such inorganic material fields as fine ceramics and new glass. We are also, most recently, seeing the emergence of materials engineering departments (in which all kinds of materials are studied), either as newly established departments, or as departments reorganized from some existing materials-related department. This emergence has been in response to recent advances in new materials research and development. This has not resulted so far in an increase in the number of university personnel retained in inorganic materials departments, but the numbers of seminars and lectures dealing substantively with fine ceramics are now increasing, and the number of students studying in this field is believed to be growing.

There is, however, a shortage of R&D personnel in the rapidly expanding fine ceramics industry, and companies are having to shift personnel into the fine ceramics field from other fields such as metal materials (cf Figure 2-12). As discussed earlier, however, fine ceramics are different from other materials in terms of material properties and utilization methods, making it necessary to conduct various kinds of training for company employees newly assigned to the fine ceramics field. And, while the number of students is becoming considerably larger, universities are experiencing an intensifying demand for courses related to fine ceramics.

Table 2-15 Comparisons of Departments, Staff Personnel

(15) 平成元年6月

(1) 年度 (2) 大学等	(7)	(3) 国立			(4) 公立			(5) 私立			(6)
		大学数	学科数	定員数	大学数	学科数	定員数	大学数	学科数	定員数	定員数
1983 (10)	無機材料	5	(8) 5	(9) 160	(7)	(8)	(9)	(7)	(8)	(9)	160
(11)	高分子	14	19	789							789
(12)	金属	17	26	1025	2	2	100	5	7	640	1765
(13)	総合	4	4	190							190
(14)	計	40	54	2164	2	2	100	5	7	640	2904
1988 (10)	無機材料	4	4	141							141
(11)	高分子	10	17	894				1	1	80	974
(12)	金属	12	17	777	2	2	100	5	6	560	1437
(13)	総合	8	12	1068				2	2	130	1198
(14)	計	34	50	2880	2	2	100	8	9	770	3750

Key to Table 2-15:

1.	Year	2.	Universities, etc
3.	National	4.	Public
5.	Private	6.	Staff personnel
7.	Number of universities	8.	Number of departments
9.	Number of staff personnel	10.	Inorganic materials
11.	Polymers	12.	Metals
13.	Combined	14.	Total
15.	June, 1989		

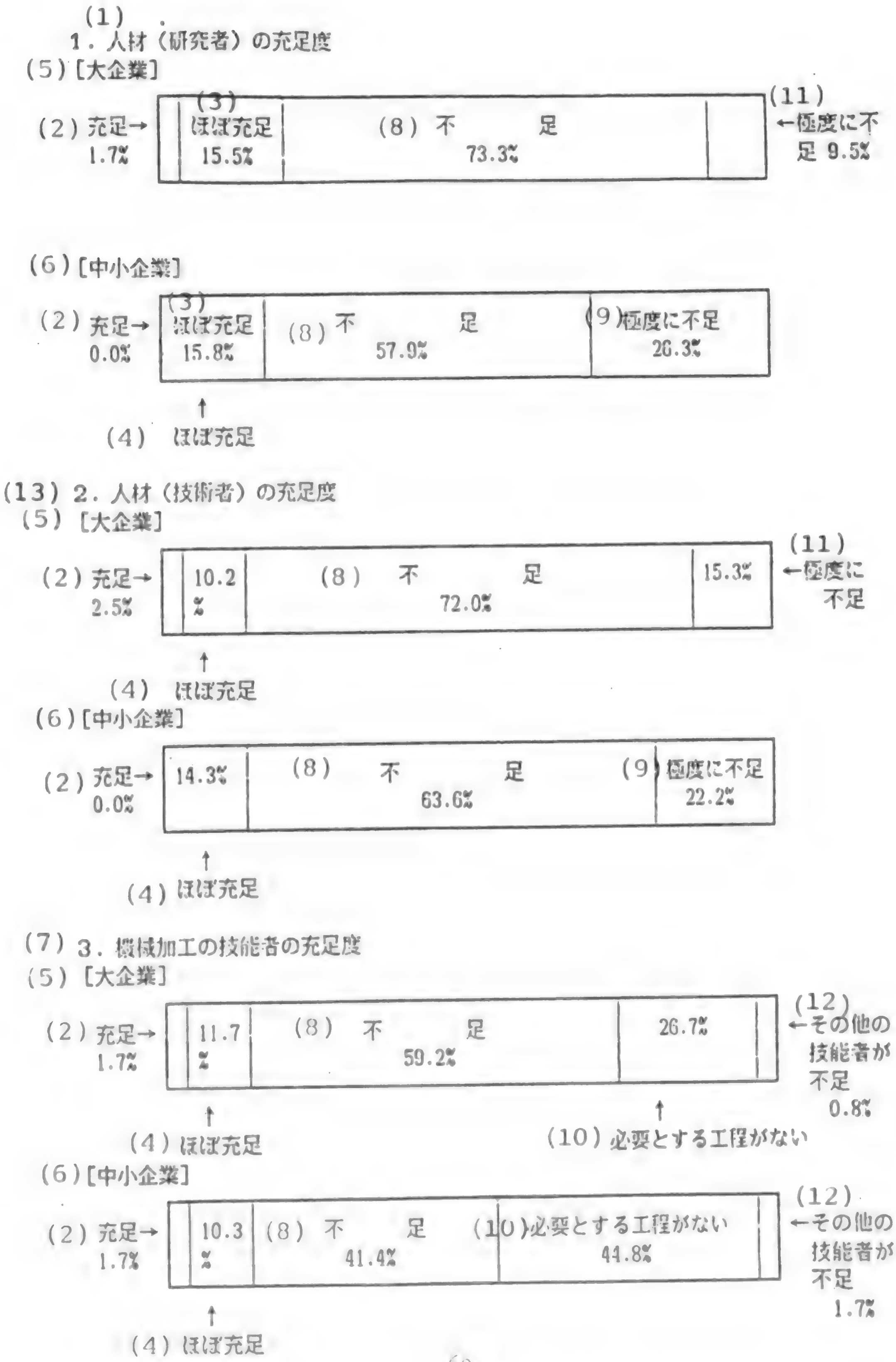
In fields like new materials, moreover, where the pace of technological advance is very brisk, one cannot rely on conventional knowledge but must continually be absorbing new information and learning. In addition to a university education that is broadly based and systematic in basic fields, personnel must be given continuing training after employment. This continuing training must be multi-faceted and include active participation in scientific associations and societies.

(4) Need for International Vision

Japan's fine ceramics industry accounts for roughly 60 percent of world production, making it the top-ranked producer nation. The technological level in this industry--from basic research to production and applications technology--is unparalleled in the world, largely due to indigenous Japanese efforts (cf Chapter 3). It is against this background that many countries throughout the world are seeking to cooperate with Japanese interests working in this field, through both governmental and private channels, and through international organizations. (Cf Table 2-16)

This notwithstanding, Japan is generally seen, in many cases, to develop its technology by importing technology from other countries, and Japan has little experience in taking an active leadership position in international cooperation. When international cooperation is actively pursued, moreover, the more industrially advanced side is expected to shoulder a larger burden in terms of capital, information, and personnel used. This tendency is unavoidable. On the other hand, however, when we look at Japanese industry, we see indeed that the size of that industry, and the technological level, are unparalleled in the world, but most fine ceramics operations are not currently profitable. In this context, it is difficult for the companies engaged in these operations to become immediately involved in international cooperation which imposes additional burdens on them. It is also safe to say that Japan is not necessarily ahead of the United States and Europe at the level of basic research in fine ceramics. Given the present situation, there is as yet insufficient awareness of the need for international cooperation. Japanese involvement in international cooperative initiatives is now on a piecemeal basis, and is not well organized.

Figure 2-12 Personnel Sufficiency



Key to Figure 2-12:

1. Personnel (research) sufficiency
2. Sufficiency
3. Nearly sufficient
4. Nearly sufficient
5. [Large corporations]
6. [Small & medium-sized companies]
7. Sufficiency of machinists
8. Insufficient
9. Extremely insufficient
10. Needed processes unavailable
11. Extremely insufficient
12. Shortage of other technicians
13. Personnel (technician) sufficiency

Key to Table 2-16 [cf next page]

1. Other Country
2. R&D cooperation
3. Industrial cooperation
4. Standardization
5. Other
6. Multilateral cooperation
7. Bilateral cooperation
8. Cooperation with developing nations
9. International conferences, etc
10. United States
11. England
12. France
13. Belgium
14. West Germany
15. Sweden
16. Canada
17. Republic of Korea
18. Australia
19. Agreement to conduct R&D on high-temperature automotive materials
20. Concluded U.S.-Japan Science and Technology Agreement in June, 88
21. Research exchanges based on high-level Japan-EC agreement(s)
22. Concluded Japan-France Science and Technology Agreement in 74
    Research exchanges
23. Joint research with national laboratories [and/on] special research operations [according to] international [agreement] in 86
24. Begin cooperation negotiations in 81; personnel exchange
25. Signed Japan-Canada Science and Technology Cooperation Convention in 8?
26. Concluded Japan-ROK Science and Technology Cooperation Agreement in 85
27. Concluded Japan-Australia Science and Technology Cooperation Agreement; exchange information between national laboratories, etc
28. Study on CGT industrial cooperation in Oct, 88
29. Agree in 79 to promote Japan-EC industrial cooperation
30. Form Japan-UK Industrial Cooperation Convention in 81
31. Establish Japan-France Industrial Cooperation Commission in 81
32. Form Japan-Belgium Industrial Cooperation Convention in 81; information exchange

Table 2-16 International Cooperation in Fine Ceramics Field

(41) ●・・・実施中、(42) ▲・・・検討中

	(1) 相手国	(2) 研究開発協力	(3) 産業協力	(4) 標準化	(5) その他
(6) 多国間	(9) 国際会議等	—	—	—	(36) ●JFCA、JFCC等
	VAMAS	—	—	●JFCA、JFCC、(35) 国立試等	—
	IEA	(19) ▲自動車用高温材料研究開発実施協定	—	—	—
(7) 二国間	(10) 米国	(20) ▲88年6月日米科技協定締結	(28) ▲88年10月CGT産業協力調査	—	—
	EC	(21) ●日・ECハイレベル協議に基づき研究交流	(29) ▲79年、日・EC産業協力の推進を合意	—	—
	(11) イギリス	—	(30) ▲81年日英産業協力定期協議を設立	—	(37) ●87年来日調査
	(12) フランス	(22) ●74年日仏科技協定締結 研究交流	(31) ▲81年日仏産業協力委員会設立	—	(38) ▲セラミックバレー構想
	(13) ベルギー	—	(32) ●81年日白産業協力協議設立 情報交換	—	—
	(14) 西ドイツ	(23) ●86年国際特定研究事業 国立試と共同研究	—	—	—
	(15) スウェーデン	(24) ●81年 協力協議開始 人材交流	—	—	—
	(16) カナダ	(25) ▲81年日加科技協力協議締結	(33) ●85年日加産業協力協議締結 人材交流	—	(39) ●JFCAとCUICACとの間で情報交換
	(17) 韓国	(26) ●85年 日韓科技協力協定締結 情報交換	—	—	(40) ●84年以来現在までに4回FCセミナーを開催
	(18) 豪州	(27) ●日豪科技協力協定締結 国立試と情報交換等	(34) ▲87年 日豪産業協力協議設立	—	—
(8) 発展途上国協力		—	—	—	▲JICA,UNIDO

Key to Table 2-16 [continued]

33. Concluded Japan-Canada Industrial Cooperation Convention in 85; personnel exchange
34. Established Japan-Australia Industrial Cooperation Convention in 87
35. JFCA, JFCC, national laboratories, etc
36. JFCA, JFCC, etc
37. U.S.-Japan survey, 87
38. Ceramic Valley protocol
39. Exchange information between JFCA and CUICAC
40. Hold four fine ceramic seminars since 84
41. Now being implemented
42. Now under study

Nevertheless, Japan has used the fruits of foreign R&D over the years in developing its technology in the materials fields. As a result, that industry has expanded, and Japan now enjoys a dominant world position in functional fine ceramics. In view of this experience, it is only natural that Japan should enthusiastically contribute to the development of testing and evaluating techniques and to the formation of databases and other common world assets--enterprises in which the United States and Europe has in the past played the larger roles. The biggest recipient of the benefits of such international activity, moreover, will be Japan--the world's leading producer nation. Take for example the field of structural materials. It is safe to assume that Japanese industry intends to participate actively in this world market. This cannot happen, however, unless international standards are put in place.

Chapter 3 Developments & Trends in Other Countries

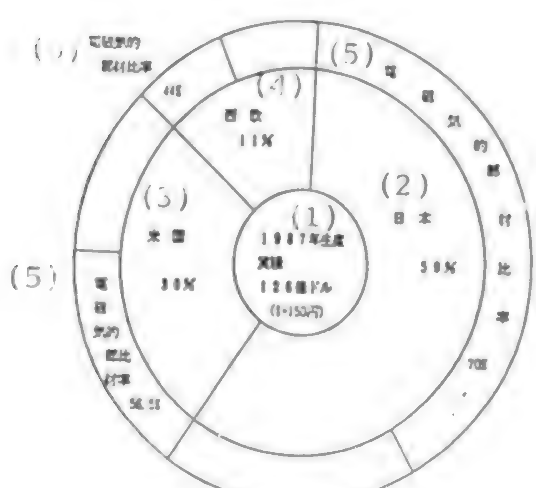
(1) Country-by-Country Trends

<1> In this country, the Japan Fine Ceramics Association has been gathering its own data and monitoring trends in raw-material and component-material markets since 1982. MITI has been compiling government statistics on electronic component materials since 1986.

In the United States and Europe, however, very little is published by the government in the way of market trends or statistics, leaving one to rely on data provided by private surveying organizations in each country. The private surveys, however, are not always conducted every year. The estimates made differ largely from one survey organization to another, moreover, making it extremely difficult to get an accurate picture of the world market.

It is estimated that component-material production in the free world totaled approximately \$12.6 billion in 1987, with the share breakdown being \$7.4 billion (59 percent) for Japan, \$3.8 billion (30 percent) for the United States, and \$1.4 billion (11 percent) for Europe. These statistics are indicative of Japan's technological and product capabilities in this field (cf Figure 3-1).

Figure 3-1 World Production (Estimates) of Fine Ceramics in 1987
(Source: Frost & Sullivan Co)



Key:

1. 1987 production total $$12.6 billion ($1 = ¥150)
2. Japan
3. United States
4. Europe
5. Percentage electromagnetic component materials

The percentages of these regional totals accounted for by electromagnetic component materials were 70 percent in Japan, 44 percent in the United States, and 57 percent in Europe, with the average annual growth rate being in the 10- to 19-percent range at the highest. The share accounted for by electromagnetic component materials is particularly high in Japan.

<2> In many cases, national governments publish summary status reports of research and development in their respective countries. In the fine ceramics field, furthermore, there is much cooperative activity between different countries, so that the status of R&D in the various countries can be understood relatively well through information exchanges between research organizations and the dispatching of R&D missions. For a comparison of technological levels between Japan, the United States, and Europe, we turn to *Trends and Problems in Industrial Technology*, published in September, 1988, by MITI, where we find the following statement. "The level [of technology] in the field of fine ceramics is higher in Japan than it is in the United States (cf Figure 3-2). In the sub-field of new functional fine ceramics basic technology, the United States is first, followed by Japan and then Europe. In certain specialized areas like ceramics for optical electronics, Japan is on top."

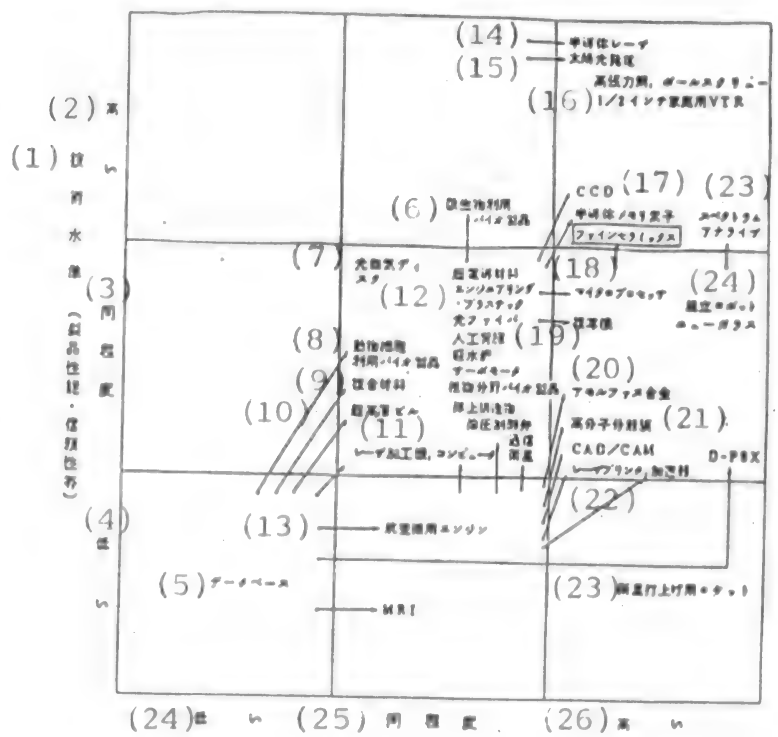
A report issued by the U.S. Department of Defense (DOD) in May, 1989, also asserts that Japan leads in the field of structural ceramics. In that regard, these two reports agree.

(3) R&D Trends in EC

<1> EC-based R&D activities have been rapidly intensified in recent years, and the scope of those activities has broadened. At the present time, R&D efforts are being strengthened for the purpose of maintaining the competitiveness of European industry in the world markets. In this context, the "Basic EC Industrial Technological R&D Plan (1987 - 1991) has been put into effect, and is being coordinated with and supplemented by various joint projects between the various member nations.

<2> Of these projects, the main ones which involve fine ceramics are the Brite/Euram project, which is part of the Basic Plan mentioned above, and the Eureka project, which is one of the other joint projects. These projects are being coordinated with private EC joint projects and with other

Figure 3-2 Changes Over 5 Years in Japanese Technological Level and Development Capabilities in High-Tech Products



Key to Figure 3-2:

1. Technological level
2. High(er)
3. About the same
4. Low(er)
5. Databases
6. Bio products using microbes
7. Optical-magnetic disks
8. Bio products using animal cells
9. Composite materials
10. Super-high-rise buildings
11. Laser machining, computers
12. Superconductors, engineering plastics, optical fiber, artificial kidneys, light water reactors, servo motors, bio products in [illeg] field, ocean-going structures, hydraulic control valves, communications satellites
13. Aircraft engines
14. Semiconductor lasers
15. Solar electricity
16. High-tensile-strength ball screws, ½-inch home VCR's
17. Semiconductor memory elements fine ceramics
18. Microprocessors
19. Copier machines
20. Amorphous alloys
21. Polymer separation films
22. Laser printers, accelerators
23. Satellite launch rockets
24. Low(er)
25. About the same
26. High(er)

Notes to Figure 3-2:

1. For the levels of the various products, the Japanese levels (compared to U.S. levels) are indicated for 5 years ago and present.
2. Origin of arrows indicates 5 years ago, point indicates present level.
3. There has been no change in categories which have no arrow.
4. Technological development power is indicated in terms of the developmental power of developmental (improvement) research. This level is generally lower than that of developmental research in applications and basic research.
5. Position of a category within a square in the diagram has no bearing on the level.

Source: Survey by Agency of Industrial Science & Technology, March, 1988

projects being conducted by separate member nations. There is also a research organization that is directly administered by the EC, namely the Joint Research Center (JRC), which conducts research in wide-ranging areas.

<3> Brite/Euram (European Industrial Basic Research/European Advanced Materials Research Project)

A) This new project was established by merging the former Brite project (1985-88) with the Euram project (1986-89). The purpose of the merger was to support R&D in an effort to provide the fundamental technology necessary for developing revolutionary industrial products and manufacturing technology. This in turn should make European technology more highly competitive, and promote technology transfers to industry (particularly small and medium-sized businesses).

B) This project is a four-year plan (1989-1992), with a projected overall budget of 496 million ecus.

C) Advanced materials development covers metallic materials, superconducting materials, fine ceramics, complex materials, new materials, and improved materials. The emphasis is on the development of these materials and processes for manufacturing them.

<4> Eureka Project (European Research Cooperation Organization)

A) This R&D project was inaugurated in November, 1985, in response to a French proposal and under French leadership. It is currently being participated in by 12 EC nations, six EFTA nations, Turkey, and 20 EC committee members. The objective of the project is to develop--through multilateral cooperation in Europe--products and strengthen production technologies which are based on advanced technologies, and thereby make European technology more competitive in world markets.

B) A total of 297 individual projects--divided into nine categories, including "materials"--are comprehended by the umbrella project. An estimated 8 billion ecus are needed for the project.

<5> The EC's Joint Research Center (JRC) is made up of four laboratories. Most of the work relating to fine ceramics is conducted at the Petten Advanced Materials Laboratory in Holland. At the Petten lab, a staff of about 50 people is engaged in research on metals, fine ceramics, and other advanced materials. The fine ceramics work may be subdivided into the following three areas.

A) Evaluation of mechanical properties (testing methods, correlation with microscopic structure, high-temperature physical properties)

B) Processing (basic research on structural ceramics structures; single-phase, complex ceramics; metal-ceramic bonding)

C) Corrosion in Various Environments

The annual budget for 1988 is approximately 20 million ecus. Each EC nation is conducting its own research and development. The priorities in this project are on standardizing testing methods and collecting data.

(4) R&D Trends in West Germany

<1> The fine-ceramics-related R&D activities in West Germany got started in the field of industrial ceramics, and mainly aluminum-oxide ceramics. West Germany was at one time the world leader in this field. Since 1976, based on these past achievements, West Germany has been working on an automotive gas turbine program, under the direction of the federal government's Ministry for Research & Technology (BMFT). This program was participated in jointly by the main West German automakers (Daimler Bentz, Volkswagen), ceramics producers (Degussa, Rosenthal, Feldmure, etc), universities, and public research facilities. The program was managed by the German Institute of Aerospace Research (DFVLR).

<2> This project was completed in 1984. It failed in achieving its initial objective of making gas turbines with an intake temperature of 1350°C and outputs of 150, 175, and 350 horsepower. (Tests went up to 1300°C, but were hampered by cracks and structural failure.) Nevertheless, the project bolstered hopes that such turbines can be made practical in the future. The research also engendered renewed awareness of the need for wide-ranging basic research.

<3> It was based on the results of this project that the BMFT "New Materials Research" program was launched in 1985. This 10-year program--which keeps track of the progress made in Japan's R&D System for Next Generation Industries (so-called Next Generation System)--focuses primarily on basic

research. The prime movers in the program are the Max Planck Metal Material Research Laboratory, the Urich Nuclear Power Research Laboratory, and a number of universities. The program is sponsored by BMFT, but the Raw Materials Project Management Department at the Urich nuclear lab (KFA) is overseeing the project (doing the office work and actual research management) in the interest of smoother research activities.

Table 3-3 1985 Fine Ceramics R&D Themes, Research Expenditure

Theme	No of Themes	Research Expenditure
Develop basic materials, production methods	14	DM 33 million
New powder manufacturing methods	8	DM 16 million
Develop mfg methods for parts prototypes	30	DM 104 million
Bonding technology	4	DM 5 million
Total	56	DM 158 million

When this program was launched in 1985, it was decided that an interim evaluation would be conducted in 3 years, that is, in 1988. At that time, the goals, priorities, and funding situation were to be reviewed and, if necessary, the program was to be completely reconsidered. When this interim evaluation was made, a need was seen in the area of structural ceramics for promoting concentrated R&D in all the manufacturing processes, as well as a need for the German ceramics producers and users (especially the automakers) to work together more closely. The total expenditure on ceramics-related R&D through June, 1988, was approximately DM 250 million (approx DM 125 million undertaken by BMFT). Both the number of research themes and the budget are expected to increase.

Chapter 4 Future Outlook

4-1 Ideals to Aim For

In the first three chapters we discussed the fine ceramics industry, looking specifically at the development history and peculiar characteristics, and at the current status of production and application. We also compared the domestic and foreign situation. This has enabled us to understand the role played by the fine ceramics industry, to see how the industry is being positioned, and to examine some of the problems now facing the industry.

In this chapter, we will try to explore the future potential of this industry, using the results of the foregoing analyses and studies, and keeping in view the economic and societal pressures that affect the industry.

<1> Spontaneous Formation of New Industry

Functional fine ceramics have already grown into an 800-billion-yen industry. More than half of this figure is accounted for by electromagnetic materials. This is an industry of major proportions. The information and electronics industries will, it is predicted, continue steadily to grow and develop. As this happens, materials development will again intensify in this field, and functional fine ceramics will grow and develop even further.

In the field of structural fine ceramics, production volumes are currently small, but the growth rate is more rapid than it is for functional fine ceramics. Notable R&D advances have been made in this field recently, and demand is expanding rapidly as ceramic-based products are being increasingly employed as automotive parts. In Japan, R&D is being conducted through various different projects, and practical implementation will be promoted as technology is developed in the private sector. This is expected to result in the very rapid formation of a large market. Also foreseen is the opening of new markets as new materials appear which combine the properties of both functional and structural materials and perform in unconventional ways. Such materials will not be subsumable under either of the conventional categories. An example would be a structural material which exhibits electrical conductivity and sensor functions.

<2> Development Through Cooperation Between Advanced, Other Industries

The applied science that is being developed in such so-called advanced industries as atomic power and energy, information and electronics, biotechnology, and aerospace only becomes fully expressed and embodied as aggregates of materials are fashioned into systems. If there is no progress in materials development, it is usually impossible to fashion a system. Hence materials form the foundation on which the advanced industries are built. Materials hold the key to development.

The materials demanded in these industries must satisfy extremely rigorous conditions. With fine ceramics it is now possible to create new performance categories and functions which could not be achieved with previously existing materials. On the other hand, users are relatively unaccustomed to handling fine ceramics, and applications technology is not well developed. Accordingly, it is strongly hoped that this industry will grow in tandem with other advanced industries.

<3> International Contribution Through International Cooperation

It is said that Japan has reached the top in terms of production volume and technological level. In the past, Japan promoted development by importing the results of foreign research and development. Now, however, Japan is expected to acquit itself as a world leader in making enthusiastic world contributions through R&D, through developing materials testing and evaluat-

ing techniques, and through industrial cooperation. In the field of functional fine ceramics, Japan is engaged actively in exporting and investing abroad. It is predicted that Japan will now become actively involved in world markets in the field of structural fine ceramics. One matter of vital concern to Japan--with its widely-developed international interests--is the international standardization of materials testing and evaluating methods. Looking ahead to future developments in the world fine ceramics market, however, these international contributions will be very beneficial to Japan. Hence enthusiastic international contribution is a must.

<4> Supporting Regional Industry

Greater regional activity is essential to the realization of balanced land-resource development. Of particular importance in this regard is the promotion of local industry to provide more employment and rejuvenate regional economies. Promoting regional industry is often not an easy task, however, due to shortages of information, human resources, and technology. One sometimes sees cases where, in the end, regional resources are not utilized.

The traditional ceramic industry [*yogyo*] has a long history, and is often based in remote regions in order to secure raw materials. Some of the companies engaged in such regionally based ceramics business are anxious to move into the field of fine ceramics. Supporting and encouraging these companies will broaden the base of the fine ceramics industry, and this in turn will further promote that industry while making significant contributions to the regional economies and regional industry.

<5> Achieving Richer, Less Stressful Society

Fine ceramic materials are used in the machine and electronics fields. Many of these products contribute greatly to the enhancement of human society. As fine ceramic materials become increasingly indispensable to such products, they contribute indirectly to the realization of a richer society. The contribution in the field of medicine--notably as materials for artificial bone and dental roots--is also significant. As material performance improves, it is expected that more medical applications will be made of fine ceramics, and the role of fine ceramics in our increasingly aging society should be large. Applications in the home are also expanding, with fine ceramics being used in kitchen knives, scissors, and other household items. The field is also making significant contributions to the environment, with fine ceramics used in catalytic carriers in automobiles. As technology becomes further advanced and demand increases, fine ceramics will no doubt contribute much in shaping a better society. The use of fine ceramics is improving heating efficiency, which translates into energy conservation. Thus fine ceramics technology will surely contribute toward solutions to our global environmental problems.

4-2 Demand Projections

We may expect the fine ceramics industry to grow and change considerably in the future. It is not easy to predict future demand from present circumstances, but we have attempted to predict long-term demand. These predictions are based on trends in technological development and applications development, trends in related industries, and forecasts on the implementation of various technologies. We first made market scale forecasts for each product group for the year 2000, then combined these results to come up with a forecast for the overall market in 2000. Next, despite the difficulties facing the development of practical products by 2000, it is possible that major breakthroughs will be made in the fine ceramics field in ceramic gas turbines, superconductor materials, and fuel cells, so we made market scale forecasts with the assumption that these technologies would all be practically implemented. Finally, in order to examine the importance of fine ceramics as absolutely indispensable materials in various industries, we made market forecasts--for the year 2000--on products and systems in which fine ceramics materials and components are used.

(1) Fine Ceramics Market in Year 2000

The market that currently (in 1987) totals 1.15 trillion yen when synthetic diamonds are included, will grow to 6 trillion yen by 2000. Electromagnetic component materials--which currently account for 70 percent of fine ceramics production excluding new diamonds--will decline sharply, as a percentage, to little more than 50 percent. In contrast to this, the market for structural materials, which is now exhibiting rapid growth, will increase greatly, and the markets for both tool and machine materials and thermal materials are expected, respectively, to reach 500 billion yen by 2000 (cf Table 4-1).

<1> Electromagnetic Materials

This market will exhibit large growth because it is linked to growth in the electronics industry. Growth will also be stimulated, we predict, by developments of such new products as compound semiconductors and new complex elements and of such new applications as actuators in piezoelectric elements and ultrasonic motors. This market, currently totaling approximately 740 billion yen, will grow to 2.9 trillion yen by 2000.

<2> Tool, Mechanical Materials

Technological advances will result in enhanced reliability and lower costs. New applications for wear-resistant materials will be developed, as will new applications in the field of precision measurement devices. Accordingly, the current market of 100 billion yen will grow rapidly to about 504 billion yen in 2000 and thereby form a new market [sic].

Table 4-1 Long-Range Market Projections for Fine Ceramics (2000)

(Units = 100 million yen)

Category	Product	Current (1987)	Forcst (2000)
Electromagnetic materials	IC boards, packages, etc	1360	3370
	Thermistors, varistors, compounds, semiconductors, etc	420	2000
	Magnetic materials	1520	3370
	Capacitors	1800	6200
	Piezoelectric elements, vibrators, etc	1200	6000
	Spark plugs	440	730
	Electromagnetic insulators, etc	660	2100
	Other	0	5100
	Subtotal	7400	28870
Tool, mechanical materials	Tool, super-hard materials	690	2320
	Wear-resistant materials	160	1370
	Other	150	1350
	Subtotal	1000	5040
Thermal materials	High-temp wear-resistant materials	100	1170
	High-temp corrosion-resistant materials	150	1800
	Other	250	1970
	Subtotal	500	4940
Chemical, medical materials	Sensors	170	1020
	Catalysts, catalytic carriers	390	980
	Biological, physiological materials	30	1950
	Other	30	560
	Subtotal	620	4510
Optical materials	Optical fiber	670	4800
	Other	250	2350
	Subtotal	920	7150
Other materials	Nuclear power-related materials, energy	0	820
	Consumer-culture items	200	1280
	Superconductor materials	0	1550
	Other	0	1000
	Subtotal	200	4650
Subtotal		10640	55160
Diamonds	Approx	820	4980
Total		11460	60140

<3> Thermal Materials

Technological development is now very intense in the area of automotive engine materials and components, and this field shows very great promise for demand growth. The market, currently at 50 billion yen, is expected to show a ten-fold growth, to 494 billion yen, by the year 2000. This is the most rapid growth predicted for any fine ceramics material. The ceramic gas turbine is not expected to become practical by 2000, but the spin-off effect of the technological development done in this field is expected to be great. As semiconductor production increases, the market for semiconductor heat-treating jigs is predicted to become large.

<4> Chemical, Medical Materials

The main products in this field are sensors, catalytic carriers, and biological materials, with outstanding growth now seen in the markets for sensors and biological materials. The demand source for almost all the sensors is for automotive oxygen sensors. This demand is increasing, and special sensors are also expected to be developed. In the field of biological and physiological materials, the formation of new markets is foreseen as medical technology becomes increasingly sophisticated and as our society becomes more aged. As a consequence, the current market scale of approximately 62 billion yen is predicted to grow to something like 451 billion yen by 2000.

<5> Optical Materials

More than half of the demand in this field is accounted for by optical fiber. The laying of trunk lines has been completed, but demand is expected to grow for users and equipment. There are also expectations for increased demand for optical elements and the development of new products. This market is currently valued at roughly 92 billion yen. We predict it to reach approximately 715 billion yen in the year 2000.

<6> Other Fine Ceramics Materials

There are expectations for market growth in materials for power generation facilities and nuclear power, as well as for such consumer-culture items as household utensils and artificial jewels. Some practical applications for ceramic-based superconductor materials are also anticipated. The current market of roughly 20 billion yen is predicted to reach something like 460 billion yen in 2000.

<7> Synthetic ("New") Diamonds

Most of the current demand in synthetic diamonds is for use in tools, but many new applications are expected to be developed. These include coatings on wear-resistant sliding components, magnetic disks, and magnetic heads, as

well as for heat sinks, semiconductor materials, optical materials, and audio products. The present market is valued at roughly 82 billion yen. A value of around 498 billion yen is forecast for the year 2000.

(2) Projected Demand After 2000 Due to Technological Progress

Very intensive R&D efforts are being focused in long-term projects on the three fields of superconductor materials, ceramic gas turbines, and fuel cells, and some applications for superconductor materials are anticipated by the year 2000. Nevertheless, substantial utilization of fine ceramics in these fields cannot be responsibly predicted until sometime later. These fields, however, will no doubt lead to tremendous breakthroughs in fine ceramics technology, and the market is expected to become extremely large. Even though no realistic market forecast can be made for the year 2000, we may expect practical applications to be made soon thereafter, and we made market estimates for each area.

<1> Superconductor Materials

Since 1986, superconductor-related materials development and process development have been rapidly intensifying, and superconductor material characteristics have been elucidated to a considerable extent. Enthusiastic R&D work is now being done to develop processes and characteristic-evaluating methods, etc. Superconductor MRI (magnetic imaging) systems are already being practically implemented in the field of medical diagnostics. If various problems in temperature level and processing technique can be resolved, applications are expected to spread very rapidly into such areas as power generators, power transmission cables, power storage equipment, magnetically suspended trains, and magnetically propelled ships. We have predicted a market of 155 billion yen by 2000. However, if the usable temperature level rises to that of liquid nitrogen, the market could reach 1.5 trillion yen, and if it rises to room temperature, the market could reach 10 trillion yen.

<2> Ceramic Gas Turbine

Ceramic gas turbines are highly suitable for use with multiple fuel types. They are also characterized by low pollution, light weight, and small size. Hence they can contribute to the resolution of global environmental problems, energy conservation, and resource conservation. Intense research is currently being done, both through a national project and various other R&D efforts. Taking into consideration trends in technological development and domestic demand for automobiles and electric power, a market of about 2 trillion yen can be predicted if automotive and power-generation applications can be practically implemented.

<3> Fuel Cells

Fuel cells are advantageous power sources in that they produce clean exhaust gases, little noise, and extremely little pollution. Since they can be located within or near cities, they are considered ideal for future power systems as urban power demand continues to increase. R&D in this field is very active. In view of electric power demand projections, the market for fine ceramics in this field can be predicted to reach around 1 trillion yen if applications in separators for fused carbonate fuel cells and electrolyte for solid electrolyte fuel cells reach the practical level.

(3) Demand Forecasts in Related Product Markets

In order to examine the importance of fine ceramics in various industries, we made market forecasts for the year 2000 for products and systems incorporating fine ceramics materials and components, and related products. We predict that this combined market will reach roughly 50 trillion yen and produce very extensive spin-off effects in related industries.

Table 4-2 Demand Forecasts in Fine-Ceramics-Related Markets in 2000

(Units = trillion yen)

	Component Materials Market	Related Products Market
Electromagnetic materials	2.9	27.0
Tool, mechanical materials	0.5	1.0
Thermal materials	0.5	4.9
Chemical, medical materials	0.5	4.0
Optical materials	0.7	5.0
Other component materials	0.5	3.3
Subtotal	5.5	45.2
Synthetic Diamonds	0.5	4.9
Total	6.0	50.1

Chapter 5 Measures for Promoting Growth of Fine Ceramics Industry

5-1 Basic Concepts

(1) New Ideas for Promoting Industrial Growth--Creative Challenge, International Contribution as Leading Nation

The Japanese basic materials industry can boast to the world that its superiority in quality control and manufacturing technology is the result of its own efforts at technological development. In the past, however, in developing materials and application technology in this industry, Japan frequently had to rely on technology learned from the advanced nations in Europe and America. In Japan, of course, the industries which made early use of the new materials developed by the aerospace industry were extremely weak compared to those in the advanced nations of the West. Hence one factor in this importation of technology from abroad was a peculiar domestic situation in which Japan could only wait for technology to be developed in Europe and America. There are many problems which cannot be overcome by the developmental efforts of the basic materials industry alone.

Today, however, the level of Japanese technology in the new materials industry, and particularly in fine ceramics, is unsurpassed in the world, and nowhere in the world are developmental efforts being conducted more broadly or intensively, from materials development to utilization. From now on, it will not be easy to efficiently develop products in a short time by learning from the advanced nations in the West. On the contrary, it is now expected that Japan should become much more active as a leading nation in areas such as basic research (where Japan has conventionally depended on the West), the development of testing and evaluating techniques (which will provide an industrial infrastructure common to all nations), database compilation, and the development of applications technology.

It has usually taken a basic materials industry about 30 years to mature into a real industry once research has been initiated, as we saw in the history of the development of functional fine ceramics in Chapter 1. It is also essential that R&D be steadily continued throughout that period, and that efforts be made to promote demand growth. Serious developmental work on structural fine ceramics began only about 10 years ago. The future is bright in this field, but long-term development efforts are of course necessary. If Japan can coordinate its efforts in this field with those of other countries, and put structural fine ceramics on a solid industrial footing, this process will provide a model case for industrial development, and Japan will move ahead as a pioneer in the fine ceramics industry.

(2) Continual Promotion of Cooperative Technological Development Between Industry, Academia, Government

Fine ceramics are already being used in electronic components and a wide variety of other fields. In order to more fully exploit the outstanding properties of these materials, however, we must continually promote technological development efforts to develop new substances, improve material performance, and develop new process technologies. As progress is made in developing materials, the relative importance of developing utilization technology will increase. At the present time, users are not very accustomed to using fine ceramics--particularly structural fine ceramics--and utilization technology has been perfected in only a few areas. But in order to develop utilization technology, ties between manufacturers and users need to be strengthened, the reliability of various components needs to be verified, and material design technology needs to be perfected. Finally, after these elemental technologies have been developed, prototypes must be subjected to trial runs to verify the reliability of entire systems. This R&D in the area of utilization technology will require enormous expenditures of money.

In order to make future R&D more efficient and promote demand growth, it is extremely important that material testing and evaluating techniques be standardized so that data can be compared. Thus R&D on these techniques is a very important task.

Wide-ranging basic research, materials development, utilization technology development, evaluation technology development, and process technology development are very closely interrelated, and it is necessary that R&D be conducted in a cooperative effort by industry, academia, and government, with mutual feedback mechanisms operative between these parties so that R&D results can be shared. The active role of the private sector in promoting such diversified R&D is of course assumed, but many of the R&D projects will require a long-term commitment and enormous funding. Unflagging R&D efforts will be necessary in order to achieve rapid development in the fine ceramics industry as the 21st century approaches. Research efforts at universities and national laboratories must also be upgraded, and R&D in the private sector should be appropriately subsidized.

(3) Government-Private Cooperation in Improving Industrial Infrastructure

Let us begin with the issue of standardization. In the past, in Japan, standardization in materials fields has taken place after the formation of a stable market, with a view to promoting smooth product transactions and distribution. In contrast to this, with materials such as structural fine ceramics for which a market is just beginning to form, "advance" standardization is needed, rather than the "follow-up" standardization that has conventionally occurred. This means that the main emphasis will be placed not on product standardization but rather on the development of standardized

testing and evaluating procedures. In the field of functional fine ceramics, a stable market has to some extent already been formed, and active international transactions are now being made, so product standards will become necessary in some cases.

Government must play a major role in developing testing and evaluating techniques and in implementing standards. The standardization implemented in the advanced western nations, however, is usually promoted by scientific societies and other private organizations more than by the government. In the United States, there is a National Institute of Standards & Technology administered by the Department of Commerce which corresponds to the National Testing Laboratory in Japan. This organization is engaged primarily in conducting experimental research which pertains to standardization, while material standards are established by the American Society for Testing and Materials, a private organization. Most of the funding for this organization comes from the sale of standard labels and other sources in the private sector. The government provides relatively little funding. Similar mechanisms are in operation in the United Kingdom, France, West Germany, and other European nations, and governmental support is limited.

The large contribution made by private industry in Japan toward standardization cannot be denied. In the past, however, Japanese industry has merely availed itself of the benefits of the standards which have been implemented at enormous cost--of capital and human effort--in the advanced nations of Europe and America. In the field of fine ceramics, however, since Japanese technology is very advanced, the conventional approach to standardization of testing and evaluation techniques--i.e. of importing the fruits of efforts made in other countries--will not be acceptable. The development of testing and evaluating techniques usually requires enormous expenditure and human labor, moreover, and the problem cannot be solved merely by the government encouraging standardization. It is good and proper, of course, for the government to take a leading role in promoting standardization. But when we consider the urgency of establishing this industrial base or infrastructure, we see how necessary it is that testing and evaluating techniques be developed and standardized through private-government cooperation and funding, as appropriate, giving due attention to related activities abroad.

The government also has a big role to play in providing more satisfactory departments and courses at universities for the purpose of training the needed personnel. These training programs at the universities cannot be relied on exclusively, however. It is also necessary to promote human resource development in the private sector through programs conducted by the scientific and professional societies, and through company-sponsored training programs.

5-2 Miscellaneous

(1) Promoting Technological Development

The R&D tasks which must be addressed in this field are listed in Table 5-1, arranged according to what auspices the research is being done under, whether university, national laboratory, national project, or private industry.

Table 5-1 R&D Themes To Be Dealt With
(Italics indicate particularly important themes)

Basic Research

Universities, National Laboratories

1. Basic research on physical properties (physical property theory, measurement methods), reinforcing (strengthening) theory, composite effect, interfaces, superconductor theory
2. Materials design (basic computer-design theory)
3. Mechanisms (powders, molding, baking, toughening)

National Projects

1. Physical properties (research on physical properties under super-high temperatures and super-high pressures in large systems)
2. *Materials design (predicting properties through computer design, development of material design systems)*

Private Industry

Basic research focused according to manufacturing application

1. Evaluation of component material properties, quality control
2. Practical implementation of material design technology (CMD)
3. High-function, complex-function materials

Materials Development

Universities, National Laboratories

New materials discovery, design
(Gradient functions, composite materials, room-temperature superconductors, intelligent materials)

National Projects

1. *New materials development (complex materials, synthetic diamonds, gradient-function materials)*
2. Improved material functions (super-heat-resistance, high toughness, large complex shapes)

Private Industry

1. Practical applications for new materials (bonding, laminating, complex-function materials)
2. New processes for practical use of materials (such as high-toughness materials, monolithic-structure materials)

Table 5-1 [continued]

Utilization (Application) Technology Development

Universities, National Laboratories

Search for new utilization systems

National Projects

1. *Utilization systems (CGT, fuel cells, high-temperature superconductors, environmental protection (industrial waste disposal, etc), aerospace materials, energy-using equipment, cogeneration, supercritical boilers)*
2. New concepts for utilization (application) design technology

Private Industry

1. Utilization systems (applications development, implementation technology)
2. Practical implementation of new utilization design technology
3. Improvement of utilization technology (bonding, process technology)

Evaluation Technology Development

Universities, National Laboratories

Evaluation techniques (longevity prediction methods, statistical methods for calculating breakdown probabilities)

National Projects

1. Standardization (testing methods)
2. *Evaluation techniques (non-destructive inspection procedures, longevity prediction techniques, material evaluation techniques)*

Private Industry

1. Standardization (product classification, coding)
2. Valuation techniques (applications for manufacturing processes)

Process Technology Development

Universities, National Laboratories

Basic research on new process technologies using new concepts

<1> Molding, baking, (highly efficient) processing, composites, bonding, surface treatment

<2> Continuous process technology for fine powder → synthesis, molding, baking

<3> Molecular-, atomic-level control processes

<4> Sol-gel techniques, bioprocesses, ion implantation

National Projects

1. Control technology (computer-based process control, intelligent manufacturing processes)
2. *Development of new processes using new concepts (large structural components using PVD, CVD; hybrid processes; molecular-, atomic-level control processes; superfine particle-making processes)*
3. Improved process technologies (complex processes, film-forming processes (large-surface, high-speed precision film-thickness control))

Table 5-1 [continued]

Private Industry

Process implementing technologies (to achieve higher efficiency, lower cost, higher production volume, greater reliability, higher precision)

<1> Powder-making technology <2> Near-net-shape molding technology
<3> Baking technology <4> Processing, machining technology
<5> Microscopic structural organization control technology
<6> Atmosphere control technol <7> Process parameter control technol

Other

Universities, National Laboratories

Databases (software, basic data accumulation, collation)

National Projects

Databases (compilation of materials database)

Private Industry

Databases (data submission)

In our universities and national laboratories, we need to intensify and broaden basic research in such areas as physical properties, and molecular- and atomic-level control, and thereby discover new substances. R&D is expected to become increasingly focused on basic research and to become more interdisciplinary. Accordingly, in promoting R&D, it will be absolutely necessary to promote joint research and information exchanges with researchers in electronic engineering, mechanical engineering, and other fields, and to promote more interdisciplinary coordination between the Japan Ceramics Association and other scientific organizations.

In the private sector, the more urgent tasks include the development of lower-cost, high-reliability process technology, the development of utilization systems, and the upgrading of such utilization technology as bonding and processing/machining techniques.

The government, finally, is already conducting numerous R&D projects, but is faced with a growing list of new developmental tasks. While continuing with the projects now underway, governmental agencies must also more fully exploit the Major Industrial Technology R&D Program (for large-scale projects) and develop advanced function-creating processing technology for the purpose of developing new processes in which control can be implemented at the molecular and atomic levels. The government also needs to move quickly to develop the ceramic gas turbine for automotive use.

In the field of new materials, in addition to development work on conventional monolithic materials, the national R&D program needs to be more involved in developing fine ceramics composite materials and synthetic-diamond semiconductor materials. There is also tremendous social demand for

the development of new utilization technologies in such areas as industrial waste disposal and super-critical boilers.

It is also important that, in our national research laboratories and projects, we develop such evaluation technology as longevity measurement techniques and non-destructive inspection procedures. This work must be carried on in tandem with development work on materials and utilization technologies. And in a field where experience and know-how must be heavily relied upon, we need to develop computer-based systems for the molecular design of materials.

(2) Aggressive International Cooperation

In order to be actively involved in making international contributions through international cooperation, we must first improve our basic posture toward international cooperation. In other words, in actively implementing policies of international cooperation, we must adopt and maintain the posture of a world leader for which the making of international contributions is an international obligation.

International cooperation is currently initiated at a number of levels, including government, university, private industry, and scientific society. These efforts are not being well coordinated, however, and this is one factor which militates against international cooperation. Hence one urgent necessity is that of setting up a domestic mechanism for promoting and coordinating international cooperation. This requires the establishment of an organization made up of involved persons in government, industry, and academia. It might be called the "Fine Ceramics International Cooperation Coordination Commission." This commission would handle all proposals for international cooperation, coordinate related domestic programs, hold international conferences for those involved, and promote further exchanges of information, personnel, and research findings.

A facility which could be called something like "International New Material Center" should also be established for the purposes of effecting uniformity and continuity in programs of international cooperation and of facilitating a unified approach to disseminating and collecting information and to exchanging personnel.

(3) Improving Infrastructure for Development of Fine Ceramics Industry

The first task is to promote the development and standardization of testing and evaluation techniques. As discussed above in section (1) "Promoting Technological Development," however, the first priority is to increase the budgets for national survey research and for related research in national laboratories and national projects. The role of government in promoting standard testing and evaluation procedures, as we said, is great. Other measures which should be studied right away include the formation of

programs for related funding for small and medium businesses and for funding the Key Technology Center, in the context of the Fine Ceramics Center--which is the main organization working to develop testing and evaluation techniques--and other organizations. And even though these efforts be carried on to the fullest extent possible by the national government and as nationally sponsored programs, in view of the importance of the R&D themes and work that are necessary, we will also need the kind of cooperation seen abroad wherein the private sector helps in providing both funding and personnel. This means that we will have to consider tax incentives and other official policies to encourage such private-sector funding.

The second task relates to database creation. To begin with, we must look into the compilation of catalog databases and literature databases. In actually compiling the databases, the utility of the database must be compared with the expense of compiling it, and the work must be coordinated with already ongoing efforts to compile databases. This work must also be based on practical schemes. As to fact databases, there is a high awareness of the need for such databases, but greater reliability in these databases is being demanded both domestically and overseas. With testing and evaluation methods not yet standardized, data discrepancies tend to be large, and reliability low. Hence the standardization of testing and evaluating methods is a prerequisite. It is also desirable that these databases--particularly the fact databases--contain data from many different countries and be usable jointly and internationally. The compilation of a database is extremely expensive, so we need to study the possibilities of sharing the cost burdens internationally.

The third task is that of human resource development, and the first thing which must be done here is to upgrade the fine-ceramics-related departments and courses offered in the universities. In recent years, the numbers of students and faculty engaged in fine ceramics at university have increased as departments have been established for materials engineering and other materials-related fields. But these numbers are still inadequate. In view of the demand from industry, universities need to increase their efforts to increase staffing in these fields. Measures need to be implemented in the private sector as well. These include the offering of related courses and seminars by the scientific societies, the provision of appropriate educational opportunities at the company or corporate level, and the employment or cross-training of personnel from other fields.

(4) Greater Role for Regional Industry

In realizing a greater role for regional activity in the fine ceramics industry, greater activity needs to be promoted in fine-ceramics exchange groups formed in various regions throughout the country, and the regionally based national and public research facilities which provide leadership to these groups need to be upgraded and strengthened. A national conference should also be held annually to exchange views, through the Fine Ceramics

Group Coordinating Conference (*Fain Seramikkus Kanren Dantai Renraku Kyogikai*), and a network needs to be created for day-to-day information exchange. This would facilitate a direct and frank exchange of information and problems between the various regions, and hence promote regional growth in the field.

In the longer term, however, these efforts should not stop at information exchange, but should be extended to the promotion of joint R&D operations between the groups or between the companies belonging to the groups.

(5) Actively Promoting Understanding, Wider Use

One of the biggest problems to be overcome in developing greater demand for fine ceramics is the fact that fine ceramics are new materials, and hence not materials which users are familiar with. In seeking to correct this problem, there is a great role to be played by exhibitions and fairs at which many users can be introduced to such new materials. Private industry should avail itself of every opportunity to broaden and deepen the understanding of the characteristics of fine ceramics, and of how they are best used. In promoting long-term demand growth in the field, ordinary consumers as well as company specialists need to be made more familiar with fine ceramics.

The marketplace has recently been stirred up by the appearance of products in which far-infrared ceramics are used. Unlike conventional ceramic products which are used in elevated-temperature applications, these new ceramics are used at room temperature, and the scientific basis for their effectiveness has not been elucidated. After evaluating the situation and looking at the results of surveys made by experts in the field, guidelines need to be issued to those involved as early as possible. Also indispensable will be the establishment of a nationwide far-infrared ceramics industry group to conduct fact-finding surveys, exchange information between businesses, formulate detailed guidelines, and see to it that everybody understands the guidelines.

Appendix 1 Modern History of Fine Ceramics

Atchison discovers SiC (1891)
Successful industrialization of superhard alloys (WC-Co) (1926)
Use of steatite ($MgO \cdot SiO_2$) in high-frequency insulator porcelain (1928)

1930————————————————————————————

Discovery of Cu-Zn and Co-ferrite magnets (1930)
Spark plugs made of high-purity (>99.9%) alumina porcelain (1931)
Development of TiO_2 porcelain capacitor (1933)

1940————————————————————————————

Discovery of strong dielectric properties of $BaTiO_3$ (1943)
Research on semiconductor properties of SiC monocrystals (1946)

1950————————————————————————————

Industrial use of tools made of sintered alumina (1951)
Discovery of PTC resistors based on semiconductor $BaTiO_3$ (1954)
GE succeeds in synthesizing artificial diamonds (1955)
Successful development of translucent alumina (1959)

1960————————————————————————————

Hot-press sintering of AlN; widening application of hot-press technology (1960)
Experimentation with optical communications using glass fiber (1964)
Animal tests begin using artificial bones, teeth, and joints made of alumina (1965)
Development of laminated ceramic capacitor (1967)
Development of ZnO porcelain varistor (1968)
Production of ceramic laminated packages begins (1969)

1970————————————————————————————

U.S. Department of Defense commissions research to develop materials and components for ceramic turbine (1971)
Sialon research becomes international (1974)
Development of quartz-based glass fiber for low-loss optical communications (1974)
Successful manufacture of SiC fiber from polycarbosilane (1975)
Toughness of partially stabilized zirconia (PSZ) interpreted as phase transformation (1975)
MITI Moonlight Project begins work on high-efficiency turbine technology; project includes development of ceramic components (1978)
ASEA company announces HIP sintering method for Si_3N_4 (1978)

1980————————————————————————————

Experimental ceramic diesel engine runs for 320 hours (1980)
MITI launches R&D System for Next Generation Industries; fine ceramics also included (1981)
Development of Si_3N_4 glow plugs, ceramic bearings (1982)
Perfection of technology for fabricating artificial bones and dental roots made of apatite (1983)
Ceramic turbochargers used in commercially marketed vehicles (1985)
Discovery of superplasticity phenomenon in ceramics (1985)
Race to develop superconductor ceramic materials (1986-)
Ceramic gas turbine development starts in MITI Moonlight Project (1988)

Appendix 2 Fine Ceramics Materials & Functional Applications
[Field Symbols: **EE** = Electrical, Electronics; **O** = Optics; **B** = Biotechnology; **C** = Chemistry; **M** = Machines; **H** = Heat-resistance, Other]

<<Single Oxides>>

Al_2O_2	**EE** Electrical insulation, IC boards, packages, electron tube envelopes, vacuum switches **O** Sodium lamps, laser oscillators **M** Wear-resistant equipment, ore/coal shutes, anti-corrosive equipment, anti-corrosive pumps, valves, slurry pumps, mechanical seals, nozzles, dies, cyclone linings, crushing & pulverizing equipment, grinding & polishing materials **H** Thermocouple protection tubes, high-temperature thermal insulation material, heat exchangers, high-temperature furnace materials
AgO	**EE** Active battery ingredients
Ag_2O	
BeO	**EE** Semiconductor heat-radiating boards, IC boards **C** Heat-resistant experiment equipment **H** Super-high-temperature probes, high-output heaters
Bi_2O_3	**EE** Fuel cells
CaO	**H** Crucibles
CoO	**EE** Gas sensors, ECD
Cr_2O_3	**M** Mechanical seals **H** Wear-resistant materials
Fe_2O_3	**EE** Magnetic recording materials **C** Paints, coatings **M** Grinding & polishing materials
In_2O_3	**EE** Transparent conducting films, fuel cell electrodes **O** Infrared reflector films
MgO	Semiconductor heat-radiating boards **O** Infrared windows
MoO_2	**EE** Active battery ingredients
MnO_2	**EE** Active battery ingredients
NiO	**EE** Fuel cell electrodes, active battery ingredients
Nb_2O_5	
ReO_2	**EE** Electrically conducting materials
SiO_2	**EE** Package feelers, vibrators **O** Optical fiber, photomasks **C** Acid-resistant containers & tubes, separation films, adsorbents, gas sensors **M** Heat radiation tubes **H** Gas sampling tubes, semiconductor heat-treatment containers
SnO_2	**EE** Transparent conducting films, gas sensors **O** Infrared reflector films
Ta_2O_5	**O** Optical waveguides
TeO_2	**O** Optical modulator elements
ThO_2	**EE** Oxygen sensors
TiO_2	**EE** Transparent conducting film, gas sensors, capacitors
V_2O_5	**EE** Active batter ingredients, resistance fast-change elements **C** Catalysts
WO_3	**EE** ECD (electrochromism), active battery ingredients
ZnO	**EE** Varistors, gas sensors, SAW elements **O** Optical waveguides

ZrO_2	**EE** Oxygen sensors, fuel cells, resistance heaters **M** Gas turbine fins, combustors, crushers & pulverizers, sea water pumps, automobile engines, scissors, kitchen knives **H** Wall materials for coal-gas conversion furnaces, high-temperature thermal insulation

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<<Complex Oxides>>

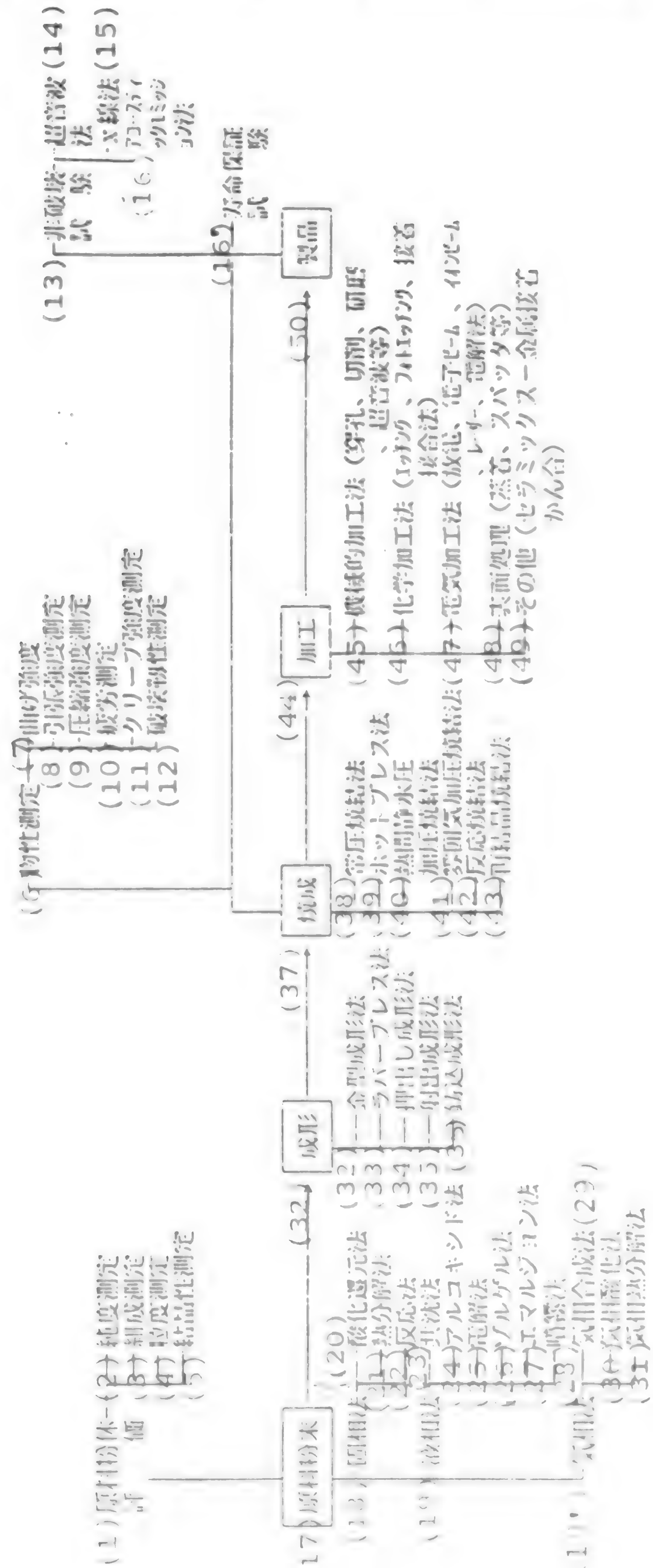
$BaTiO_3$	**EE** Capacitors, vibrators, sensors, secondary electronic radiators
$Ba_2NaNb_5O_{15}$	**O** Optical modulator elements
$Ba(PbBi)O_3$	**EE** Superconductor materials
$La_{1-x}Ba_xCuO_4$	**EE** Superconductor materials
$YBa_2Cu_3O_{7-x}$	**EE** Superconductor materials
$Bi_2Sr_2Ca_2Cu_3O_y$	**EE** Superconductor materials
$Tl_2Ba_2Ca_2Cu_3O_y$	**EE** Superconductor materials
$BaFe_{12}O_{19}$	**EE** Recording media, magnetic shielding, permanent magnets, magnetic bubbles
$Bi_{12}GeO_{20}$	**EE** SAW elements
$Bi_4(GeO_4)_3$	**O** Optical modulator elements
$CaWO_4$	**O** Fluorescent bodies
$GeO_2 \cdot Sb_2O_3$	**O** Infrared optical fiber
$Gd_3Ga_5O_{12}$	**EE** Magnetic bubble element substrates **O** Lasers
$In_2O_3SnO_2$	**EE** Transparent conducting films
$LaCrO_3$	**EE** High-temperature heating units
$Ln_3Fe_5O_{12}$	**EE** Magnetic body isolators for use at high frequencies, gyrators, magnetic bubble elements **O** Optical isolators (Note: Ln = Y, other rare earths)
La_2TiO_7	**EE** Temperature-compensating capacitors
$Li_2B_4O_7$	**EE** SAW elements **O** Pyroelectric sensors, optical modulator waveguides
$LiNbO_3$	**EE** SAW elements **O** Pyroelectric sensors, optical modulator waveguides
$LiTa_3$	**EE** SAW elements **O** Pyroelectric sensors, optical modulator waveguides
$LiTi_2O_4$	**EE** Superconductor materials
$(MZn)FeO_4$	**EE** Magnetic heads, magnetic cores, humidity sensors, isolators (Note: M = Mg, Mn, Ni, Co)
Mg_2TiO_4	**EE** Temperature-compensating capacitors
$MgCr_2O_4 \cdot TiO_2$	**EE** Temperature sensors
Nb_2TiO_7	**EE** Temperature-compensating capacitors
$SrCeO_3$	**EE** H, H_2O sensors, fuel cells
PLZT	**EE** Image storage **O** Optical shutters
$PbO \cdot TiO_2 \cdot Cr_2O_3$	**EE** Copier machine sensors
PZT	**EE** Piezoelectric ignitor elements, vibrators **O** Pyroelectric sensors
$ZnCrO_4 \cdot LiZnVO_4$	**EE** Humidity sensors
$PbO \cdot B_2 \cdot O_3$	**EE** Electronic component sealing materials
YAG	**O** Lasers

<<Complex Oxides--Silicates>>	
$3Al_2O_3 \cdot 2SiO_2$	**C** Scientific equipment **H** Baking setters
$MgO \cdot SiO_2$	**EE** Electrical insulation materials
$2MgO \cdot SiO_2$	**EE** Electrical insulation materials
$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$	**H** Heat-resistant impact components, heat exchangers
$Li_2O \cdot Al_2O_3 \cdot 4SiO_2$	**H** Heat-resistant impact components
$ZrO_2 \cdot SiO_2$	**H** Heat-resistant components
$CaO \cdot SiO_2$	**O** Fluorescent bodies
$MgO \cdot SiO_2$	**O** Fluorescent bodies
$ZnO \cdot SiO_2$	**O** Fluorescent bodies
$KMG_3AlSi_3O_{12}(F, OH)_2$	**O** Electrical insulation materials **M** Processed ceramics
Zeolite	**C** Catalysts, adsorbents, gas separation agents
<<Complex Oxides--Phosphates>>	
$Ca_3(PO_4)_2$	**B** Artificial teeth, artificial bones & joints, skin terminals
$Ca_3(PO_4)_2 \cdot Ca(F, Cl)_2$	**O** Fluorescent bodies
$Ca_{10}(PO_4)_6(OH)_2$	**B** Artificial teeth, artificial bones, artificial joints, skin elements, artificial blood vessels, artificial bronchal tubes
<<Carbon>>	
Diamonds	**EE** Heat-radiating substrates, semiconductor acoustic needles **O** Windows **B** Scalpals **M** Cutting tools, polishing tools, dies
<<Carbides>>	
B_4C	**M** Cutting tools **H** Nuclear reactor materials
SiC	**EE** IC substrates, resistance heaters, high-temperature semiconductors, blue light-emitting diodes **M** Polishing & grinding materials, heat-resistant equipment **H** Furnace materials, heat-resistant devices & components
TiC	**M** Cutting tools
WC	**M** Cutting tools, pressure-resistant & heat-resistant devices & components
TeC	**O** Optical recording
<<Nitrides>>	
AlN	**EE** IC boards **O** Infrared transparent materials **M** Heat-resistant jigs **H** Heat-radiating boards
BN	**EE** Boron-diffusion sources for semiconductor use, electrical insulation materials, heat-radiating boards **O** Infrared microwave polarizers **C** Glass molding jigs, crucibles **M** Cutting tools **H** Nuclear fusion materials
Li_3N	**EE** Battery materials
Si_3N_4	**C** Anti-corrosive materials **M** Gas turbine materials, engine materials, bearings, cutting tools **H** Aluminum molds, metal processing jigs
Sialon	**C** Anti-corrosive materials **M** Gas turbine materials, engine materials, bearings, cutting tools **H** Aluminum molds, metal processing jigs
TiN	**H** Decorative materials

<<Silicides>>	
$MoSi_2$	EE Resistance heater elements, LSI wires M Machine parts
<<Halides>>	
CaF_2	O Infrared windows, antiglare films
CeF_2	O Infrared windows, antiglare films
CsBr	O Infrared windows, antiglare films, prisms
CsI	O Infrared windows, antiglare films
KBr	O Infrared windows, antiglare films
LiF	O Infrared windows, antiglare films, prisms
MgF_2	O Infrared windows
NaCl	O Infrared windows, antiglare films, prisms
Li_2MX_4	EE Lithium batteries (Note: M = Mg, Mn, Fe, Co, Cd)
$ZrF_4 \cdot BaF_2$	O Infrared fibers
ThF_4	O Antiglare films
<<Chalcogenides>>	
As_2S_2	O Infrared fibers
AsS	O Infrared fibers
CdS	EE Optic conductor elements O Antiglare film, fluoresc bodies
CdSe	EE Image pick-up tubes O Infrared windows
CdTe	EE Solar cells O Antiglare films
$Cd_xHg_{1-x}Te$	EE Optical conductor elements
GaAs	EE IC gun diodes, solar cells, light-emitting diodes
GaP	EE Light-emitting diodes
Ga(As, P)	EE Light-emitting diodes
Ga(Al, P)	EE Light-emitting diodes
(Ga, Al)As	O Lasers
InAs	EE IC's, hole elements
InP	EE Solar cells
InSb	EE Hole elements, optical conductor elements
$(Sb,Bi)_2(Te,Se)_3$	EE Electronic cooling elements
MoS_2	M Solid lubricants
PbTe	EE Piezoelectric elements
(Pb, Sn)Te	EE Optical conductor elements
SeS	EE Optical conductor elements
SbSe	O Infrared fibers
TeSe	O Optical memories
ZnS	O Fluorescent bodies
ZnSe	O Infrared windows
<<Borides>>	
LaB_6	EE Thermionic emission materials
TiB_2	EE Electrode materials M Polishing/grinding materials
ZrB_2	M Polishing/grinding materials
<<Complex Ceramics>>	
$Al_2O_3 \cdot TiC$	EE Magnetic heads M Cutting tools, wear-resistant tools
$Al_2O_3 \cdot ZrO_2$	M Wear-resistant tools
$Al_2O_3 \cdot$mullite	H Heat-resistant jigs

(Key Technology Center--Survey of Trends in New Materials Technology, 1986)

Appendix 3 Fine Ceramics Production Methods, Technology



Key to Appendix 3:

1. Raw-material powder evaluation
2. Purity measurement
3. Composition measurement
4. Granularity measurement
5. Crystallinity measurement
6. Physical property measurement
7. Bending strength
8. Tensile strength measurement
9. Compression strength measurement
10. Fatigue measurement
11. Creep strength measurement
12. Toughness measurement
13. Non-destructive tests
14. Ultrasonic
15. X-ray
16. Acoustic emmission
16′ Useful life guarantee test
17. Raw-material powder
18. Solid phase
19. Liquid phase
19′ Gas phase
20. Oxidation-reduction
21. Thermal decomposition
22. Reaction method
23. Coprecipitation
24. Alcoxide method
25. Electrolysis
26. Sol-gel method
27. Emulsion method
28. Spray method
29. Gas-phase synthesis
30. Gas-phase oxidation
31. Gas-phase thermal decomposition
32. Molding
32′ Die molding
33. Rubber press
34. Extrusion molding
35. Injection molding
36. Casting
37. Firing [baking, sintering]
38. Normal pressure firing
39. Hot press
40. Hot static-water-pressure firing
41. Pressurized firing
42. Reaction firing
43. Recrystallization firing
44. Processing
45. Machining (boring, cutting, grinding, ultrasonic machining)
46. Chemical processing (etching, photoetching, bonding)
47. Electrical processing (arc, electron beam, ion beam, laser, electrolysis)
48. Surface processing (vapor depositing, sputtering)
49. Other (ceramics-metal bonding, etc)
50. Finished products

Appendix 4 Nationally Sponsored Technological Development

The national government is promoting the development of fine ceramics materials and related systems through various projects and programs, and through the national testing and research facilities (cf Table 4-1). We will now discuss the more important of these efforts.

(1) Fine Ceramics (Next Generation System)

In this R&D endeavor, the objective is to develop fundamental element technologies for the purpose of using ceramic materials in coal gasification turbines. More specifically, this involves developing the following materials.

<1> High-strength heat-resistant ceramics for use at temperatures in excess of 1400°C in turbine stator blades

<2> High-strength heat-resistant ceramics for use at temperatures in excess of 1250°C in turbine rotor blades

To achieve these goals, controlled fabrication processes need to be developed, involving raw-material synthesis technology and molding/firing technology. Along with this, processing and bonding techniques also need to be developed. Other tasks include the development of design and evaluation techniques suitable for ceramic materials, which tend to be brittle, and the development of surface reinforcing material technologies and toughness-enhancing technologies.

According to the overall plan, the research time-frame is divided into three periods. The first period (fiscal 1981 - 1983) focuses on test piece shapes, and the second (fiscal 1984 - 1987) on model components of simple shape. The goal during these periods is to develop materials which satisfy these various demands, as well as the necessary production processes. The goal in the third period (fiscal 1988 - 1992) is to achieve the targeted properties in model components having shapes that are close to actual components under near-actual conditions. And finally, all of these R&D results are to be reviewed by testing and evaluating model components which correspond to those usable in a coal-gasification ceramic gas turbine (cf Figure 4-1).

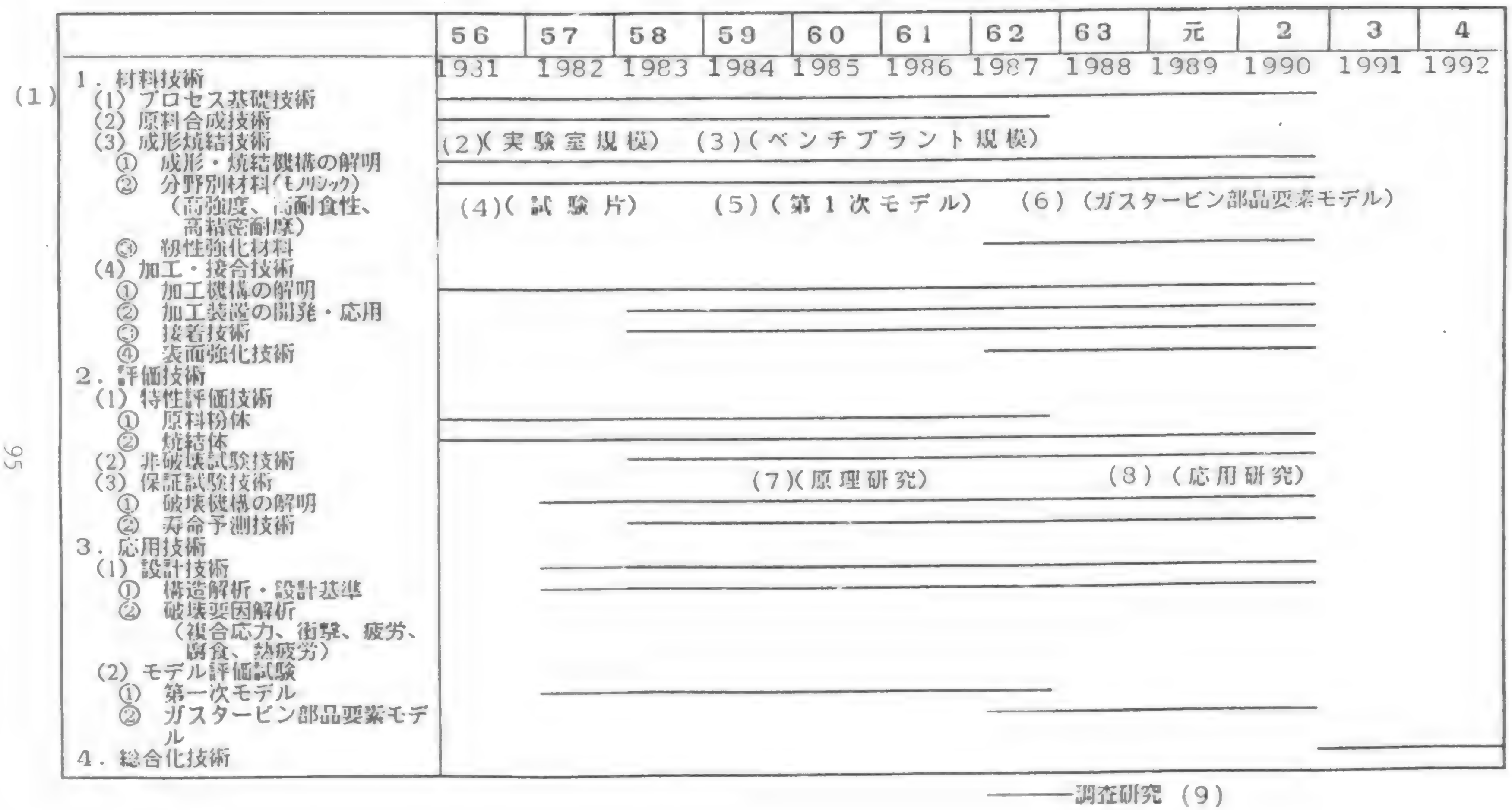
Research and development is being advanced by six national testing and research institutions and by the Fine Ceramics Technology Research Union. The first period ended with fiscal 1987, and the results were set forth in "Fain Seramikkusu Jisedai Kenkyu no Ayumi [Progress of Nest-Generation Fine Ceramics Research]." Goals are now being set for the third period and R&D work is being continued.

Table 4-1 Status of Fine-Ceramics Technological Development in Japan

Field of Development Focus	Materials Development: Basic R&D	Materials Development: Applications	System Development
Research Field			
High-temp structural materials	Next Generation System		
Superconductors	Next Generation Sys	Moonlight Proj	(Moonlight Proj)
Gas turbines		Moonlight Proj	(Moonlight Proj)
Advanced materials supertolerant to harsh environments	Next Generation System		
Fuel Cells		Moonlight Proj	(Moonlight Proj)
Ultra-advanced processing		Large projects	(Large projects)
Water recycling		Large projects	(Large projects)
Atomic Energy		Next-generation atomic-energy equipment	Next-generation atomic-energy equipment
Research Organization			
National testing & research inst	Mechanical Engineering Laboratory Chemical Technology Research Lab Govt Indus Research Institute, Osaka Govt Indus Research Institute, Nagoya Electrotechnical Laboratory Govt Indus Research Institute, Kyushu Natn Inst Research in Inorg Materials		Mechanical Engineering Lab National Aerospace Laboratory

( ): Priority field of overall project (when not fine-ceramics-related)

Figure 4-1 Next-Generation Fine Ceramics Projects



Key to Figure 4-1:

1. 1. Materials technology
(1) Basic process technology
(2) Raw-material synthesis technology
(3) Molding & firing technology
<1> Elucidation of molding & firing mechanisms
<2> Materials (monolithic) by field (high-strength, highly corrosion resistant, high-precision wear-resistant)
<3> Toughness-enhanced materials
(4) Processing, joining technology
<1> Elucidation of process mechanisms
<2> Development of processing equipment, applications
<3> Bonding technology
<4> Surface-reinforcing technology
2. Evaluation technology
(1) Property evaluating technology
<1> Raw-material powders
<2> Fired materials
(2) Non-destructive testing technology
(3) Verification testing technology
<1> Elucidation of destruction mechanism
<2> Longevity predicting technology
3. Applications technology
(1) Design technology
<1> Structural analysis, design standards/criteria
<2> Destruction factor analysis (complex stress, impact, fatigue, corrosion, thermal fatigue)
(2) Model evaluation & testing
<1> First-stage models
<2> Gas turbine component factor models
4. Integration technology

2. (Laboratory-room scale) 3. (Bench-plant scale)
4. (Test pieces) 5. (First-stage model)
6. (Gas turbine component factor models)
7. (Basic principle research) 8. (Applications research)
9. ----Survey research

(2) Ceramic Gas Turbine (Moonlight Project)

A gas turbine is a type of engine. In conventional reciprocal engines, the fuel is specifically limited (to gasoline, diesel fuel, etc). The gas turbine engine is not so limited, however, and can run on many different kinds of fuels. It also is lightweight, small in size, and produces little pollution. It does suffer, however, from the shortcoming of poor thermal efficiency. To resolve this problem, the turbine intake temperature must be made very high, and the blades must be kept from cooling. It is hoped that

these objectives can be achieved by using fine ceramics, which excel in heat resistance.

Fine ceramics are brittle materials, however, and so are not amenable to design procedures which are based on metallic materials. In this regard, non-destructive inspection procedures must be developed and refined in order to guarantee reliability. In view of the significance of the ceramic gas turbine for energy policy, and in the interest of refining fine ceramics component technology, development work on a ceramic gas turbine (300-kW class) for cogeneration applications began in 1988 as part of the Moonlight Project sponsored by the Agency of Industrial Science & Technology. The R&D period extends over 9 years, starting in 1988, with a total R&D budget of 16 billion yen (cf Figure 4-2).

(3) High-Temperature Superconductor Ceramics Project (Next Generation System, Moonlight Project)

Since 1988, research work on superconductor ceramics and related subjects has been going on as part of the superconductor material and superconductor element R&D being done under the Next Generation System of the Agency of Industrial Science & Technology (cf Table 4-2) and as part of the R&D being done on superconductive power generation technology in the Moonlight Project (cf Table 4-3).

In this research and development, R&D pertaining to superconductor materials and elements is being pushed ahead at six government industrial research institutes, at the International Superconductor Industrial Technology Research Center, and in the New Functional Element R&D Association. R&D on superconductive power generation technology is being done at four government industrial research institutes and in the Superconductive Power Generation Equipment & Materials Technology Research Union.

(4) Advanced Materials Supertolerant to Severe Environments (Next Generation System)

In the aerospace field, structural materials are demanded which are not only lightweight, but also very strong and highly rigid at temperatures in excess of 2000°C. Materials used in nuclear fusion reactors and other atomic energy applications must not only exhibit good mechanical properties under high temperatures, but also high tolerances to high pressures and to radiation. In seeking to develop structural materials which can be used in such severe environments, it will not be enough merely to improve the properties of conventional materials. What is urgently needed is to begin work on developing new advanced materials which exhibit the required supertolerance to severe environments.

The Agency of Industrial Science & Technology is working in this field within the framework of its R&D System for Next Generation Industries (so-

called Next Generation System). This work began this year, and will extend over an 8-year period. Researchers are working with matrices of complex materials made of carbon and Ti-Al intermetallic compounds. High-performance fibers (including fine ceramics fibers) are being developed to strengthen these matrices, as are techniques to combine and mold the fibers and matrices. In addition, simple intermetallic compounds are also being developed as structural materials, particularly on Ti-Al and Nb-Al(Mo-Si) systems, with the focus on materials design, basic materials development, and processing and molding technology.

Key to Figure 4-2 [cf next page]:

1. 1. Heat-resistant ceramic material R&D
   2. Element technology R&D
   3. Design, trial-run research
      (1) Basic design
      (2) First-stage design trial-run research
      (3) First-stage design trial-run research
      (4) First-stage design trial-run research
   4. Social compatibility research
      (1) Studies on environmental integrity
      (2) Studies on utilization systems
   5. Performance evaluation
2. 1988   3. 1989
4. Ceramic materials R&D
5. Technology for making components from ceramic materials
6. Basic research on element technologies (compressors, combustors, turbines, heat exchangers, bearings, monitoring and control, etc)
7. Basic design   8. Basic model GT [(900°C) / (1200°C)]
9. Studies on environmental integrity
10. Loading mode analysis; studies on economy, operations management, etc
11. Performance evaluations on ceramic materials, element devices, and turbine systems
12. Interim evaluations
13. [*continuation of text given in "6" above*]
14. Pilot CGT prototype (1350°C)
15. [*continuation of text given in "10" above*]
16. [*continuation of text given in "11" above*]

Figure 4-2 Ceramic Gas Turbine R&D Project
Energy-Saving Technology R&D Program (Moonlight Project)

(2)	昭和63 1988	(3) 平成元 1989	2 1990	3 1991	4 1992		5 1993	6 1994	7 1995	8 1996
(1) 1. 耐熱セラミック部材の研究開発	(4)セラミック部材の研究開発					中				
	(5)セラミック部材の部品化技術									
2. 要素技術の研究開発	(6)要素技術の基礎研究（圧縮機、燃焼機、タービン、					(12)	熱交換器、軸受、計測制御等)(13)			
	(6)要素技術の試作研究（圧縮機、燃焼機、タービン、						熱交換器、軸受、計測制御等)(13)			
3. 設計試作運転研究 (1)基本設計	(7) 基本設計					間				
(2)第1次設計試作運転研究		(8) 基本型GT（900 ℃)								
(3)第1次設計試作運転研究			(8)基本型CGT（1200℃)			評				
(4)第1次設計試作運転研究							(14)パイロットCGT試作（1350℃)			
4. 社会適合性研究 (1)環境保全性の検討			(9)環境保全性の検討			価				
(2)利用システムの検討			(10)負荷形態の解析、経済性、運転管理等			(15)	の検討			
5. 性能評価	(11)セラミック部材、要素機器及びタービンシステム					(16)	の性能評価			

Table 4-2 Basic R&D Projects on Superconductor Materials, Elements

1. R&D Timeframe

   1988 - 1998 (10 years)

2. R&D Goals

   A. Superconductor Materials

   Develop basic technology for finding superconductor substances and rendering them into suitable materials, and develop superconductor materials which provide the high critical temperature, high critical current density, and high critical magnetic field necessary for industrial applications.

   B. Superconductor Elements

   To develop the basic and applications technologies necessary for superconductor elements having new functions made possible by the use of super-high-speed elements and superconductor materials.

3. Specific R&D Themes

   A. Superconductor Materials

   〈1〉 Basic Superconductor Material Technology
   - Property evaluation & structural analysis of superconductor substances
   - Search for new high-temperature superconductor substances

   〈2〉 Superconductor Material Development
   - Design & synthesis of superconductor substances capable of new functions
   - Revolutionary process technologies
   - Material evaluation technology

   B. Superconductor Elements

   〈1〉 Basic Superconductor Element Technology
   - High-performance film molding technology
   - Ultra-fine process technology
   - Search for new element functions

   〈2〉 Superconductor Element-Fabricating Technology
   - Element design & production technology
   - Element evaluation technology

Table 4-3 Outline of Superconductor Power Generation Technology R&D Plans

1. R&D Timeframe

1988 - 1996 (8 years)

2. Specific R&D Themes

A. Superconductor Wire R&D

B. Superconductor Generator R&D

<1> R&D on slow-response excitation model generator
<2> R&D on super-[high-]speed excitation model generator
<3> Research on element technologies for pilot generator
<4> Development of rotor element technology

C. Overall System Research

<1> System research
<2> Survey research on induction effects
<3> Research on cable magnet element technology

D. Cooling System R&D

E. Evaluation Technology

(5) R&D on Next-Generation Atomic Energy Equipment

Managing the security of equipment in atomic power plants is of supreme importance in guaranteeing the safety of the facility and improving the operating rate. Not surprisingly, therefore, great amounts of capital and time are allocated for this purpose. There is also heightened demand now for long-cycle operating schedules to improve the operating rate. In order to facilitate such long-cycle operations, equipment reliability must be raised and useful equipment life expectations must be lengthened. The Next-Generation Atomic Energy Equipment Development Project is seeking to employ such new materials as fine ceramics which have various peculiar properties in order to increase the life-span of light water reactor equipment and components, and make these more reliable and maintenance-free.

A research and development project is now underway at the Next-Generation Atomic Energy Equipment Development Laboratory [*Genshiryokuyo Jisedai Kiki Kaihatsu Kenkyujo* of the Technical Research Union [*Gijutsu Kenkyu Kumiai*]. This is a 9-year project, commissioned by the government, that began in 1985 with a budget of approximately 14 billion yen. The aim of the project is to

find ways to use new materials--which excel in such physical and chemical stability factors as resistance to heat, wear, and corrosion.

(6) Fine Ceramics Research at Government Industrial Research Laboratories

Under the auspices of the Agency of Industrial Science and Technology (AIST), designated research projects (meaning large-scale research projects recognized as extremely important, and including research commissioned in the private sector) such as the development of high-strength ceramics, are being done within the framework of the R&D System for Next Generation Industries (so-called Next Generation System). In addition to this, however, some 214 special themes have been under research at 16 government industrial research laboratories administrated by AIST. These research themes are smaller in scale than the designated research projects, but are nevertheless important, and do not include research commissioned to private organizations. Of these 214 special themes, 23 involve fine ceramics. These 23 themes are being researched with a total budget of 252 million yen (cf Table 4-4).

Table 4-4 Special Fine-Ceramics Research Under Auspices of AIST

(Units: 1000 yen) [Each research theme is followed by PER (Fiscal Years of Research Period), LAB (Name of Research Laboratory), 89 (Fiscal 1989 budget), and 90 (Fiscal 1990 Budget).]

Techniques for evaluating the dynamic physical properties of highly elastic, heat-resistant materials PER 1988-1989 LAB Nat Res Lab of Metrology 89 18,543 90 13,374
Research using solid-phase bonding of new materials PER 1985-1986 LAB Mechan Engin Lab 89 19,030 90 10,458
Fabrication technology for ionic conductive glass thin films PER 1989-1992 LAB Govt Indus Res Inst, Osaka 89 --- 90 15,399
High-performance transparent ceramic thin film technology PER 1989-1992 LAB Govt Indus Res Inst, Osaka 89 --- 90 17,475
Synthesis of graphite complex inter-layer compounds PER 1989-1991 LAB Govt Indus Res Inst, Osaka 89 --- 90 14,409
Controlling the structure of whisker composite ceramics PER 1988-1991 LAB Govt Indus Res Inst, Osaka 89 12,318
Halide glass PER 1986-1989 LAB Govt Indus Res Inst, Osaka 89 11,204 90 10,442
Fine ceramics analysis and evaluation technology PER 1989-1992 LAB Govt Indus Res Inst, Nagoya 89 --- 90 12,671
Laser processing of structural, highly functional ceramics PER 1989-1992 LAB Govt Indus Res Inst, Nagoya 89 --- 90 12,986
Enhancing functionality of high-temperature superconductors PER 1988-1990 LAB Govt Indus Res Inst, Nagoya 89 5,406 90 6,391
Development of photosensitive ceramic materials PER 1987-1991 LAB Govt Indus Res Inst, Nagoya 89 8,780 90 7,862

Tough fiber-composite ceramics PER 1986-1990 LAB Govt Indus Res Inst. Nagoya 89 9.285 90 10.669

Functional ceramic porous bodies PER 1985-1989 LAB Govt Indus Res Inst. Nagoya 89 9.489 90 8.357

Carbon-based materials using gas-phase thermal decomposition PER 1986-1990 LAB *Koshiken* [Pub. Fund Research] 89 14.180 90 13.265

New techniques for fabricating ultra-microscopic granules PER 1988-1991 LAB Govt Indus Res Inst. Hokkaido 89 7.358 90 9.202

Development and utilization of highly functional inorganic fibers and non crystalline materials PER 1987-1990 LAB Govt Indus Res Inst. Hokkaido 89 12.948 90 13.364

Basic research on high-temperature sliding properties of carbon materials PER 1987-1990 LAB Govt Indus Res Inst. Kyushu 89 --- 90 8.891

Development of functional carbon materials from carbon mesophase PER 1989 1992 LAB Govt Indus Res Inst. Kyushu 89 --- 90 5.010

Production technology for multi-functional microsphere PER 1987-1991 LAB Govt Indus Res Inst. Kyushu 89 9.400 90 10.540

Porous chaff ceramics production PER 1987-1990 LAB Govt Indus Res Inst. Kyushu 89 10.114 90 10.547

Development of high-temperature plastic boride ceramics PER 1987-1990 LAB Govt Indus Res Inst. Kyushu 89 10.496 90 10.856

Magnesium pyroborate fiber PER 1987-1990 LAB Govt Indus Res Inst. Shikoku 89 10.397 90 10.092

Intercalation composite materials PER 1987-1991 LAB Govt Indus Res Inst. Tohoku 89 4.776 90 7.652

Research themes completed previous year (7 themes) 89 70.488 90 ---

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TOTALS: 89 244.217 90 252.222

Appendix 5 Inter-Company Cooperation in Fine-Ceramics R&D as Reported by News Media

Company Name	Cooperating Compan(y/ies)	Cooperative Project
Asahi Chemical Indus	Shin Nihon Chemical Indus Clayburn Ceramics	Development of machinable ceramic products
Asahi Glass Co Ltd	Nippon Carbite	Full coop in electronic materials (estab new co)
	Mitsubishi Motors Corp	Joint development of ceramics for automotive parts
	NKK	Joint development of silicon nitride sintered bodies
	Mitsubishi Heavy Indus	Heat-resistant structural materials and components
	British Nuclear Fuel Ltd	
	Lion Corporation	Bioceramic dental crowns
	Ishihara Pharmaceuticals	Aluminum titanate machinable ceramics technology
	Hokuriku Yogyo	Share technol, move seriously into machinablu ceramic
Asahi Optical Co	Nat Defense Academy, Asst Professor Tsuru	Develop separator that can quickly separate & collect high-purity T lymphocytes (using FC as separation agent)
	Tokyo Medic & Dental Univ	Develop reinforcing bone filler using hydroxy calcium apatite
Ishikawajima-Harima	Toshiba Corp, Koyo Seiko	Develop ceramic bearings for aircraft engines
Izumi Automotive Ind	Adiabatic (USA)	Pool capital, technol to jointly develop adiabatic engine using FC
Iwao Jiki Kogyo	Yocho Gyogu	Share technology on fishing line guides, fishing reels
NKK	Swedenasia [from kana]	Fine ceramics powder processing techniques
	Unizon	Electro-ceramics
	TYK, Govt Indus Res Inst, Osaka	Successful devel of thialon-boron nitride composite with reactive baking method

Govt Indus Res Inst, Osaka	Kurimoto Ltd	Develop low-cost method of improving toughness by mixing alumina and steel powder, and sintering
	Daihen	Prototype fine-ceramic electrical bond[ed/ing] unit
Osaka U, Indus Res Lab, A.Prof Miyamoto	Sumitomo Electric Indus	Develop new combustion baking process
Univ of Osaka Prefec	Osaka Fuji Kogyo	Perfect FC molding technology using slip-cast method
Onoda Cement	Asahi Glass Co Ltd	Alumina products
Nat Inst of Res in Inorganic Materials (Sci & Tech Agency)	TDK	Succeed in normal-temperature firing of Perovskite-type piezoelectric ceramics
Kanebo Ltd	Kobe Steel Ltd	Joint development of element technology for fuel cells
Kawasaki Steel Corp	Kawasaki Rozai	Joint development of BN powder
Kansai Elect Power	Hitachi Ltd	Development of prototype water-sealing unit to prevent water getting into generators in hydroelectric plants (Prototype uses silicon carbide)
Kyushu Refractories	Tokyo U/Prof Yanagida Chiba Tech/A Prf Shimizu	Develop ceramic paper with potassium titanate fiber
Kyocera Corporation	Nippon Piston Ring	Joint development of engine-compartment valve mechanisms
	Isuzu Motors Ltd	Joint development of ceramics for use in diesel engines
	Kyoura Electronics	Joint development of temperature sensors in which ceramics and semiconductor elements are integrated
	Eguro Tekko	Joint development of shafts, main shaft assemblies for small precision NC lathes
	Fujikino	Joint development of fine-ceramic valves
	Ishikawajima-Harima Heavy	Automotive parts
	Sansei Seisakujo	Scissors for use in dentistry
	Tokyo Sokuhan	Joint development of measurement probes and masters for FC-made air micrometers

Kyocera Corp [cont]	Sanpo Shoji	Development of FC-made knives
Gov Indus Res Inst, Kyoto	Sanwa Chemical	Jointly develop resin binder for FC injection molding
Kubota Steel	Gov Indus Res Inst, Osaka	Development of silicon-nitride heat-resis : fine ceramics
Inst of Chem Tech, Agency of Indus S&T	Ibiden	Development of porous silicon carbide
Shiko Giken	Ibiden	Development of high-speed brushless motors using ceramic dynamic pressure bearings
Shinagawa Refractor	Sauda [from kana] Co	Acquire technol for ceramic-fiber insulation material
	Okayama University	Develop artific dentures made of high-strength zirconia
	Tokushu Paper Mfg Co	Develop zirconia paper
Nippon Steel Corp	Kurozaki Refractories Co	Research on making high-strength composit ceramics; develop mullite ceramics
	NGK Spark Plug Co	Colloid research, sol-gel method research
	Asahi Glass Co	Develop ZrB_2 thermoelectrical protection tube (joint operation on heat-resistant thermometer)
	NTT	Joint research on electronics-related new materials, including superconductor materials, FC
	Phillips, Nippon Chemicon	Form joint venture. Produce fine-ceramics electronic components
	Kubota Ltd, Nippon Tungsten Co	Develop Cr_3C_2 ceramics. Skid button applications
Sumitomo Chemical Co	SFE Technology	Form Sumi-Chem NFE; manufacture and market multilayer ceramic capacitors
	Kanebo	Cosmetic applications of titanium white made into thin chips
Sumitomo Metal Indus	Narumi Seito	Develop elbos, bends made of ceramic-metal composites

Sumitomo Cement	Govt Indus Res Inst Osaka Osaka University	Develop ceramic joining technology
Sumitomo Elec Indus	Victor Company of Japan	Diamond speaker diaphragms
Sumitomo Spec Metals	Tohoku U, Prof Kawakami	Develop high-speed optical-comm shutter using ceramics
Naruji U, Prf Ozaki	Nippon Steel Corp Giken	Succeed in ceram thin-film sintering with CO_2 gas laser
Seibu Gas	Totsu	Develop, market ceramic gas burner caps
Tamagawa Univ Prof Machida	Nippon Piston Ring	Develop methods of joining diverse materials such as metals, ceramics, and plastics
Chichibu Cement Co	Tokyo Inst of Technology	Develop mfg method for making zirconium ultrafine powder
Tsubakimoto Preci- ion Products	Kyocera	Develop ceramic boring screws
TDK	Tokyo Dental University	Develop porous hydroxy apatite
	Lion	Develop dental materials made of apatite hydroxide
TYK	NKK	Sialon boron nitride composites
Central Res Inst of Elec Power Industry	Hitachi Ltd	Develop ceramic turbine stator blades for gas/steam combined electric power generation
Toa Nenryo Kogyo	Kurume University	Develop fibrous hydroxy apatite for artificial bones
Tokai Konetsu Kogyo	Nippon Seidojo	Development of high-speed degreasing oven for FC
Tokyo Gas Co	Osaka Gas, Toho Gas, Tomoe Shokai	Develop quiet boilers for use with ceramic burners
	Toshiba Ceramics	Develop radiant tubes made of silicon carbon ceramics
Tokyo Univ of Ag As Prf Tsutsumi	Toyota Koki, Toto Ltd, NEC	Prototype ultra-high-precision lathes
Token Sangyo	Monin-Haré Co (France)	Perfect mass production of ceramic balls for bearings made of partially stabilized zirconia
Toshiba Corp	Toyota Motor Corporation	Ceramics, gas turbine, engine joint research
	Komatsu Ltd	Joint development of ceramics for diesel engines

Company Name	Cooperating Compan(y/ies)	Cooperative Project
Toshiba Corp [cont]	Toshiba Ceramics	Si_3N_4 silicon monocrystal mfg method (joint R&D)
	Koransha Co, Ltd	> Develop forming technol based on nitride ceramic slip casting method > Joint develop of FC products; develop engine parts
	Koyo Seiko Co, Ltd	Joint develop of silicon nitride bearings
	Cummins (U.S.A.)	Formed company to market FC products
	Marukon Denshi	Develop niobium oxide laminar ceramic capacitors
Toshiba Ceramics	Gasukuro Kogyo	Produce semiconductor equipment (formed new company)
	Tokuyama Soda Co, Ltd	Formed Tokuyama Ceramics
	Kyoritsu Ceramic	Estab STK ceramics research lab with joint financing
Toho Gas	Noritake Company Ltd	Develop ceramic heat exchangers
Toyo Soda Mfg Co	Toppu Kogyo, Daiko Rozai	Develop zirconia pliers
	Govt Ind Res Inst Nagoya	Develop high-purity mullite
	Sophia University	Develop fine-ceram elements that bend under elec potentl
Toyo Bearing	Mitsui Seiki	Silicon-nitride bearings
Toray Industries Inc	Arusu Hamono	Joint develop of zirconia-based scissors
	Matsushita Electric Works	Joint develop zirconia-based hair clipper blades
	Maruto Hasegawa Kosakujo	Develop lightweight tweezers (FC for tip)
	Nippon Tungsten	Tech tie-up with FC. Devel insulated ZrO_2 screw driver
Tokuyama Soda Co Ltd	Tokyo Inst of Technol, Chiba University	Develop machinable aluminum-nitride ceramics
Toyama Prefec Ctr for Indus Technol	Jokin Kasei	Develop casting & forming methods for bolts and nuts
Niigata Engineering	Koransha	Jointly develop injection tube for injection molders
Nichias Corporation	Burner International	Jointly develop ceramic-fiber heat exchanger

Company Name	Cooperating Compan(y/ies)	Cooperative Project
JGC Corp (Nikki)	Nippon Fine Ceramics Ind	Develop valves for minute gas volume adjustments for use in high-vacuum applications (Use FC for parts)
Nissan Motor Co Ltd	Hitachi Ltd	Automobile parts
Nisshin Toki	Shishin Cutlery	Jointly develop scissors made of zirconium fine ceramics
Nippon Carbon	Shugo Keibi Hosho, Tokyo University/Prof Yanagida	Develop infrared sensors using silicon-carbide fiber
NGK Insulators	Cummins (USA)	Ceramic diesel engine
	Ishikawajima-Harima Heavy	Automobile parts
	Nissan Motor Co Ltd	Automobile parts
	Chubu Electric Power Co	> Heat-resistant products for boilers > Develop burner tips for electric power boilers > Develop slurry pump for thermoelec pwr plants using FC
	Matsuda	Develop all-ceramic whirlpool chamber; begin mass produc
Nihon Kagaku Togyo	Toyo Soda Mfg Co Ltd	Jointly develop partially stabilized Zr (PSZ) applicatns
	Showa Denko KK	Develop mullite; joint effort to develop market
	Kikui Tessseisakujo	Develop FC-processed hair-cutting scissors
Ulvac Corporation	JAERI	Develop metal-ceramic bonding technology
Nihon Cement Co Ltd	Nippon Ceratech	Create lab within central laboratory of Nippon Ceratech
	Ashizawa	Develop silicon-nitride mixer blades
Japan Ceramics Asso	NGK Insulators, Narumi Seito, Nikko	Form "Artificial Clay Technology Research Union" (tentative name); share technol with Nagoya Gov Indus Res Instit; seek to develop artificial clay
NGK Spark Plug Co	Riken	Jointly develop ceramics for diesel engines
	Nissan Motor Co Ltd	Automobile parts
	Yuasa Battery Co Ltd	Form Ceramic Battery
	ICI	Manufacture ceramic honeycomb

Company Name	Cooperating Compan(y/ies)	Cooperative Project
NGK Spark Plug [cont]	Barnitron	Electronic filter circuits using piezoelectric devices
	Gov Ind Res Instit-Nagoya	Joint develop of SiN_2O sintered bodies
	Aichi Medical University	Begin clinical tests on zirconia artificial joints
Noritake Co Ltd	Shirwood Refractories	Manufacture of ceramic cores
	Tokai Dental College	Develop material for FC-made dentures
	Toyota Motor Corp	Develop ceramic nozzles for welding auto parts
	Okumuragumi KK	Develop ceramic blade tips for cutting holes in concrete shielding used in atomic reactors
Hitachi Chemical Co	Carborundum (SOHIO)	Form joint venture company "Hitachi Carborundum"
Hitachi Metals Ltd	Nissan Diesel	Jointly develop ceramics for diesel engines
	Koransha	Fine ceramics cast molding technology
	Lucas Cookson Thialon	Acquisition of thialon ceramics technology
Filton	Mitsui Eng & Shpbldg Co	Joinly develop porous ceramics
Fuji Valve Co Ltd	TRW	Start developing valves for ceramic engines
Nat Defense Acad, Tohoku University	Riken	Develop alumina, silicon-carbide whiskers, and zirconia complex baked ceramics
Gov Ind Res Instit--Hokkaido	Denki Kagaku Kogyo, Sumitomo Metal Trading Co	Joint research on produc of high-purity, high-density ceramics from rice hulls
Hokkaido Industrial Testing Station	Tanaka Kogyo, Hokkai Danro	Develop alumina, zirconia oxide ceramic materials; research on practical applications
Marusu Ineyaku	Kurume Steel Works	Develop ceramic ladles (for nonferrous metal furnaces)
Mitsubishi Mining & Cement	Sprague Electronics Co	Contracted to exchange technology on laminated ceramic capacitor materials and manufacturing processes
	Yoshitomi Pharmaceutical Industries	Agree to mfg and mkt bone reinforcing material based on apatite hydrochlorate

Company Name	Cooperating Compan(y/ies)	Cooperative Project
Mitsubishi Heavy Industries	Iwao Jiki Kogyo	Ceramic heat exchangers
	Fujimori Kogyo	Jointly develop ceramic light/heat-shield sheet
	JAERI	Successfully test large ceramic rotating bodies made of silicon nitride; to devel vacuum pump for nuclear fusion
	Tokyo Electric Power Co	Seek to develop high-temp ceramic gas turbine using stationary blades
	NGK Insulators Ltd	Developing ceramic films and systems for separating compressible gases
Mitsubishi Elec Corp	Shizuoka Industrial Paper Testing Station	Develop alumina paper
Inst Phys & Chem Res	Nippon Light Metal Co Ltd	Succeed in forming AlN skin on metallic Al surfaces

Appendix 6 Organizations Involved in Fine Ceramics--By Region
[GIRI: Government Industrial Research Institute]

Name	Business Office
<Hokkaido>	
Hokkaido Regional Technology Promotion Center--New Ceramics Mfg Technology Development Committee	
<Tohoku>	
Tohoku Machine & Electronics Industry Association	
Iwate Prefec Materials Applications Research Society	GIRI--Iwate Pref
New Materials (Fine Ceramics) Research Society	GIRI--Fukushima
Aizu Fine Ceramics Research Society	GIRI--Aizu, Wakamatsu
<Kanto>	
Fine Ceramics Research Society	Tochigi South Prefec Indust Guidance Ctr
New Ceramics Utilization Technol Development Office	GIRI--Shinagawa Pref
Fine Ceramics Research Society	Niigata Pref Indus Technology Center
Ceramic Process Research Society	Occupational Training Academy
Nagano Prefec Fine Ceramics Technology Research Soc	GIRI--Nagano Pref
Ceramics Research Committee	Japan Asso of Materials Test & Technol
Chushin Fine Ceramics Research Society	Nagano Prefec Small Business Guid Ctr
Nagano Pref Flame-Coating Technology Research Society	GIRI--Nagano Pref
Nagaoka New Ceramics Council	Nagaoka Technopolis Development Organ
New Materials Applications Research Society	Shizuoka Pref Indus Technology Center
<Chubu>	
Aichi Prefec Ceramic Product Industry Cooperative--Fine Ceramics Committee	
Ceramics (Glass) Research Society	Nagoya Municipal Indus Research Lab
Tokoname Fine Ceramics Council	Tokoname Ceramics Technology Center
Gifu Prefec Ceramic Product Industry Cooperative Association--New Ceramics Development Committee	
Advanced Technology Development & Research Society	Mie Pref Ceramics Testing Station
Banko Ware High-Tech Council	Banko Tojiki Kogyo
Toyama Prefec Ceramics Research Society	Toyama Pref Indus Technology Center

Name	Business Office
<*Chubu*--contin>	
New Industrial Materials Research Society	GIRI--Ishikawa Pref
<*Kinki*>	
New Ceramics Council	Osaka Pref Industrial Technology Res Inst
Kyoto Ceramics Research Society for Youth	
Fukui New Ceramics Research Society	
Ceramic Cutlery Development & Research Society	Miki Cham Com & Indus
Kinki Region Industrial Technology Liason Conference --Ceramics Committee--New Ceramics Subcommittee	GIRI--Osaka
<*Chugoku*>	
Chugoku Region Fine Ceramics Technoforum	Chugoku Rgn Technol Promotion Center
Okayama Tobi Fine Ceramics Research Society	
<*Shikoku*>	
Kagawa Prefecture New Ceramics Research Society	Kagawa Pref Indus Technology Center
Shikoku Industrial Technology Promotion Center	
New Materials Util Research Society for Sm Business	Aichi Pref Indus Technology Center
Kochi Prefecture New Ceramics Development Council	GIRI--Kochi Pref
<*Kyushu*>	
Kyushu Fine Ceramics Technoforum	Kyushu Industrial Technology Center
Arita New Ceramics Research Society	Oaritayaki (Coop)
Nagasaki Prefecture Fine Ceramics Research Society	
Tsukumi Municipal Fine Ceramics Technol Res Society	Tsukumi City Hall
Kyodokumiai (Coop) Fine Ceramics Research Center	Tsukumi Coal Coop
New Ceramic Product Development & Research Society	Kagoshima Pref Indus Technology Center

Appendix 7 Fine-Ceramics Organization Profile

Name:	Nippon Fine Ceram Asso	Fine Ceram Center	New Diamond Forum	Nippon Ceram Asso
Formed:	November 15, 1986	May 7, 1985	July 26, 1985	August 25, 1927
Representative:	H. Suzuki, Chairman Hon Chrmn, Showa Denko	K. Iwata, Chairman Toshiba Consultant	S. Saito, Chairman Prof Emer, Tok Tech	K. Inamori, Chrmn Chairman, Kyocera
Number of Employees:	Approx 220 companies	Aprx 240 companies Sml-busin patrons	Approx 200 members	Approx 7000 members
Operations:	Related to fine ceramics industry: 1. Collect & provide information 2. Industrial, distribution, trade surveys 3. Standardization surveys 4. Promote int'l industrial cooperation, etc 5. Sponsor workshops, forums, research societies on market, technology developments 6. Spread knowledge, promote domestic, foreign relations, provide liaison bet organizatns	1. Research on clarifying, evaluating tests & their results 2. Research surveys on standardization of test evaluatn methods 3. Free up test equipment 4. Technological guidance, advice 5. Collect, supply tech information 6. Develop human resources 7. Int'l exchange	Seeks to improve & spread academic & technical knowledge through exchanging research personnel, technicians involved in new-diamond technology	1. Survey research on ceramics industry & chemical technology 2. Collect & provide information 3. Sponsor forums for announcing research, workshops, debates 4. Publish periodical(s), books 5. Present awards 6. Promote exchange & cooperation bet domestic, foreign organizations
Business Scale (FY88):	170 million yen	1.07 billion yen	60 million yen	250 million yen

Appendix 9

A) BMD (Brittle Material Design) Program

This program was conducted from 1971 to 1979. Gas turbine components were implemented in ceramics for the first time. Ford and Westinghouse were commissioned by the DOE to develop ceramic combustors and turbine rotors--Ford for automotive use and Westinghouse for electric power plant use.

B) CATE (Ceramic Application for Turbine Engine) Program

GM-Allison, under commission from the DOE from 1976 to 1980, employed small engines for trucks and busses as test engines, and replaced metal components with ceramic components, one after another. A total of 78 components were implemented in ceramic materials, including gas generator turbine blades and turbine nozzles, and operational experience was built up. The goals were a maximum temperature of 1240°C and a 20% reduction in fuel costs, but neither of these was attained. Nevertheless, this program generated valuable information for engine applications which was used in the AGT project that followed.

C) AGT (Advanced Gas Turbine) Project

This project was conducted by the DOE from 1979 to 1987. Unlike previous projects, this was not a project in which the metal components of conventional gas turbine engines were implemented in ceramics. The goal was to develop a ceramic gas turbine from the ground up.

In the AGT project ceramics were used in the critical high-temperature regions. The goals were to achieve 30% greater efficiency than the gasoline engine, low environmental impact, and fuel diversification in a ceramic gas turbine engine for use in advanced automobiles.

As organized, the project was funded by DOE (total development costs = $129.5 million), and project management was provided by NASA's Louis Research Center. DDA (GM-Detroit Diesel Allison/Pontiac) tested a dual-shaft version and Garrett a single-shaft version.

The development goals of the AGT project are listed in Table 9-1.

As a result of the AGT project, the applications technology for gas-turbine ceramic components was greatly advanced, but the temperature and durability goals were not achieved. The gains of this project were taken over by the currently on-going ATTAP project.

Table 9-1 AGT Project Goals

- -- Improve running fuel efficiency at least 30% compared to gasoline engine.
- -- Satisfy federal emissions standards. (Using DF No 2) (g/mile)
  HC </= 0.41 CO </= 3.4 NO </= 0.4 Part </= 0.2
- -- Use multiple fuel types. (Gasoline, diesel, alcohol, shale oil)
- -- Satisfy federal standards for noise, vibration, and safety.
- -- Maintain same levels of reliability and durability as engines currently used.
- -- Maintain same initial and life costs as engines currently used.
- -- Provide acceleration that is safe and satisfactory to consumers.

D) ATTAP (Advanced Turbine Technology Applications Project)

The goals of the ATTAP project are to take over where the AGT project left off, achieve further technological advances, create technology for developing ceramic components for use in automobile gas turbines, and develop the durability needed to make ceramic applications practical. Specifically, the objective is to perfect an engine with a turbine intake temperature of 1,371°C and a durability of 3,500 hours (corresponding to traveling a distance of 100,000 miles). This is a 5-year project (1987-1992) that is scheduled to have a total budget of $50 million.

The development goals for the ATTAP project are listed in Table 9-2.

Table 9-2 ATTAP Goals & Tasks

- -- Create a database for ceramic materials and, based thereon, develop analytical techniques with which ceramic components can be designed
- -- Verify integrity of design techniques through component testing
- -- Improve ceramic component manufacturing processes
- -- Improve component testing techniques
- -- Evaluate reliability and durability of ceramic components in engines

As organized, the project is funded by DOE and managed by NASA. The main contractors are Allison Gas Turbine Div (reorganized structure of DDA) and Allied Signal Aerospace Company (reorganized structure of Garett). As a result of the AGT project experience, the two contractors are not competing with each other as in AGT, but are organized so as to organically cooperate with each other. This project is also supported by the Oak Ridge National Laboratory, through the latter's High Temperature Material Laboratory built in 1987 at a cost of $19 million.

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